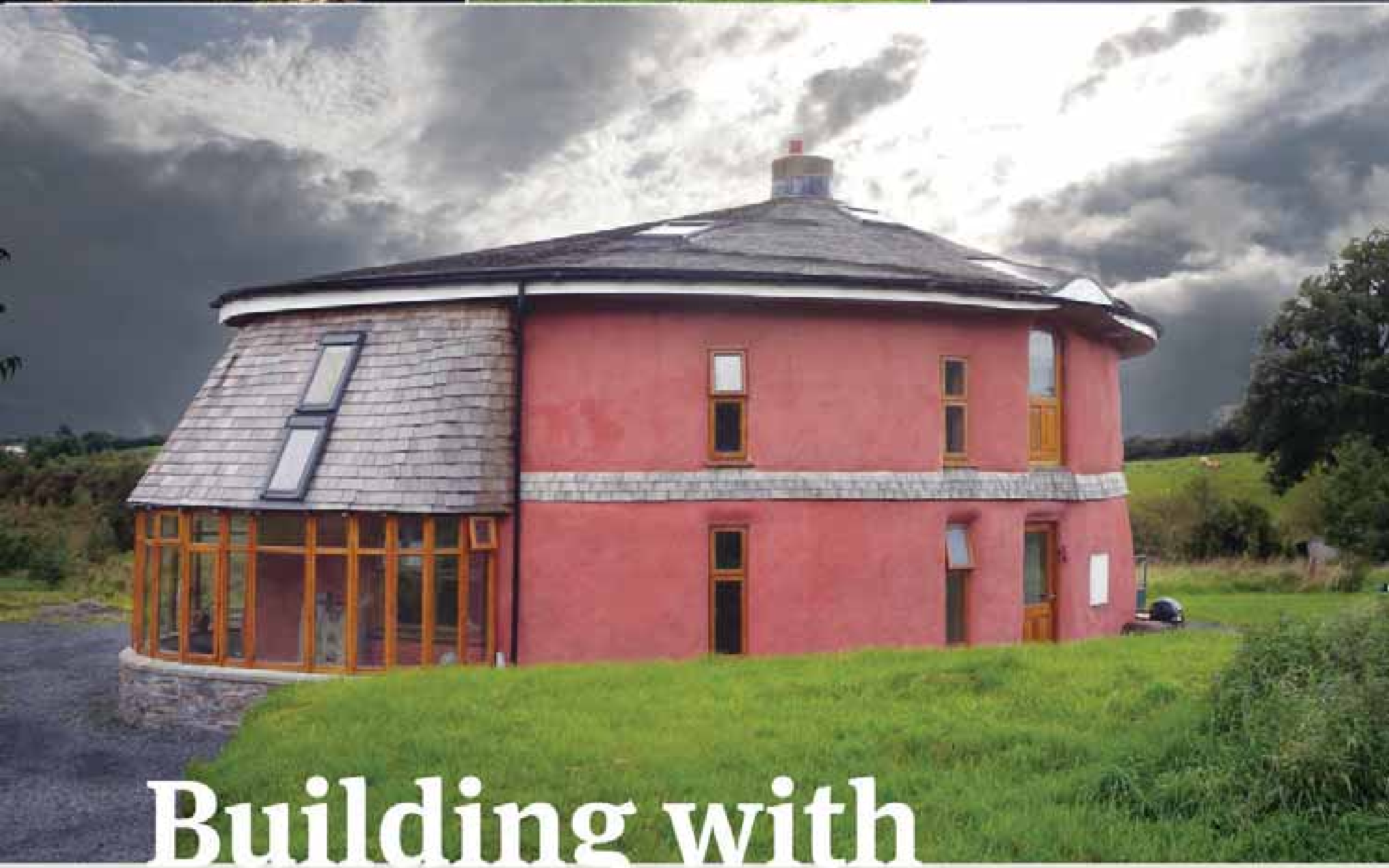

Building with Straw Bales

Revised & updated edition

A PRACTICAL GUIDE FOR THE UK AND IRELAND

BARBARA JONES

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ABOUT THE AUTHOR

Barbara Jones FRSA is the founder and director of amazonails, a not-for-profit social enterprise based in West Yorkshire and the leading company for design, consultancy, training and support in strawbale building and the use of natural materials in construction. Amazonails has pioneered many types of cement-free foundations – appropriate for many buildings, not just those of strawbale design – through the Building Regulations process, and is currently building social housing with North Kesteven Council in Lincolnshire. The company's aim is to empower ordinary people to become involved in the construction process, and to build simple, beautiful, thermally efficient buildings that don't cost the Earth. In 2009 Barbara was awarded a Woman of Outstanding Achievement Award by the UK Resource Centre for Women for Discovery, Innovation and Entrepreneurship in the field of Science, Engineering and Technology (SET).

Buildings by amazonails that have won awards include Penwhilwr, a two-storey loadbearing strawbale house in St Dogmaels, Wales, which won the Grand Designs Eco-home of the Year in 2008; a compressive frame saleroom built for Sworders Ltd in Essex, a fine-art auctioneer company, which won the East of England Sustainability Award and a Commendation in the International Awards from the Royal Institute of Chartered Surveyors (RICS) in 2009; and Shelf library extension, built for Calderdale Council, which won the Halifax Courier Environmental Design Award in 2009.

All buildings cited in this book were designed by or in consultation with amazonails, and/or were built by amazonails or with the help of amazonails' on-site training. Where 'we' is used in the text in the context of building practice it refers to amazonails.

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I am wholly indebted to the amazonails team, and to our wider community, for their input, suggestions and tremendous support in many different ways that has enabled me to rewrite this book. Bee Rowan remains a truly inspirational teacher, whose critical eye keeps me on my toes and whose opinion I value highly. Kuba (Jakub) Wihan honours me with his insight and wisdom. Emma Appleton, Sophia Godfrey, Heather Crabtree, Rachel Julian and Michelle Gaffaney – thank you. Without all of you this book would not be as complete.

Chapter 1

WHY BUILD WITH STRAW BALES?

Strawbale building makes sense. It offers us a radical way to solve many of the issues facing construction with respect to thermal efficiency, carbon footprint and cost. It's far more than just a wall-building technique; it's a completely different approach to the process of building itself. Like all innovative ideas, it has been pioneered by the passionate and practised experimentally by those with the vision to see its potential. Its background is grassroots self-build: it is firmly based in that sustainable, 'green building' culture that has brought to the construction industry many new and useful ideas about energy efficiency and environmental responsibility.

A typical plastered straw wall has a U-value of 0.13, more than twice the insulation that Building Regulations require.

This method of building is now entering mainstream construction, used by firms who see its value in terms of cost-effectiveness, sustainability, ease of installation and energy efficiency. The building method itself is based on a block system, making the designs very easy to adapt from one project to another, and giving great flexibility in its use.

Working with straw is unlike working with any other material. It is simple, flexible, imprecise and organic. It will challenge your preconceptions about the nature of building and the correct way of doing things – and not everyone will be able to meet this challenge. The simplicity of straw can be disarming, or alarming. If you need complexity for security, then this may not be for you. Don't be put off by nursery tales about the big bad wolf – we should be wise enough to realise that the wolf probably worked for the cement manufacturers! And there are plenty of examples of professionally finished, durable strawbale buildings, as illustrated in the colour pages in this book – so read on, and make up your own mind.

Straw as a building material excels in the areas of ease of installation, affordability and energy efficiency. Council houses of almost PassivHaus standard are currently being built for £110,000 for a three-bed semi. Of interest to the homeowner is the huge savings in heating costs, owing to the buildings' super-insulation. Potential savings are up to 75 per cent compared with a conventional modern house. A typical plastered straw wall has a U-value (see page 120) of 0.13, more than twice the insulation that Building Regulations require. Furthermore,

strawbale buildings appear to store latent heat – they perform in a similar way to heavyweight materials, even though they are not masonry.

The accessible nature of straw as a construction material means that even those unfamiliar with the building process can participate in it. This opens the door for interest groups to work together on joint projects. Strawbale houses are quick to build and engender an excitement and motivation that gets the job done. This makes them ideal for housing associations and local authorities to manage as joint projects with tenants and contractors. The atmosphere on a strawbale building site is qualitatively different from that found on the vast majority of other sites. It is woman-friendly, joyful, optimistic and highly motivated. Knowledge and skills are freely shared, and cooperation and teamwork predominate, all of which factors have a positive effect on health and safety on site.

One of the best features of strawbale building is the opportunity it provides for creative fun, enabling you to design and build the sort of space you'd really like.

This book is aimed at self-builders as well as the construction industry. It is meant to give clear and straightforward information about how to build houses with bales of straw. Since this is a simple and accessible wall-building technique available to almost anyone, it is ideal for self-builders as well as for mainstream builders at the forefront of sustainable house building. The language and descriptions, particularly of first principles, and of how and why we build with straw, are necessarily basic to ensure full understanding by everyone.

Throughout this book you will be encouraged towards the best possible way of doing things with a simple, straightforward and common-sense approach. One of the best features of strawbale building is the opportunity it provides for creative fun, and the way in enables you to design and build the sort of shape and space you'd really like. It lends itself very well to curved and circular shapes, and can provide deep window seats, alcoves and niches due to the thickness of the bales. It's also a very forgiving material, can be knocked back into shape fairly easily during wall raising, doesn't require absolute precision, and can make rounded as well as angular corners. Partly owing to its great insulation value and partly because of its organic nature, the inside of a strawbale house feels very different from a brick-and-block one, with a cosy, warm quality to it and a pleasing look to the eye. The beauty of straw (apart from its aesthetic beauty) is that it combines very high insulation properties with great loadbearing potential: it is a material that is building block and insulation all in one.

Different styles and opinions have grown up around the world as bale building has spread. What was suitable in one climate has not proved to be best practice in others, and availability and cost of materials vary from country to country. However, there have been wonderfully imaginative adaptations to conditions. The main concerns in Ireland and the UK have been to do with:

- adequate design of foundations to deal with moisture while impacting on the earth as little as possible

- the effect of moisture on straw
- weather protection in general.

Most of the differences in technique in this climate are to do with foundation design, the predominant use of loadbearing methods and the type of render used as a weatherproof coating. We have been able to draw on the rich knowledge of the past, using ideas that have been tried and tested over centuries. In many respects, the requirements of strawbale buildings are essentially the same as those of traditional cob (earth) buildings. They have high plinth walls, self-draining foundations, and large overhangs to the roof – 'a good hat and a good pair of boots', as cob builders used to say. They are also constructed of breathable materials and must not be waterproofed (although they must be weatherproofed). Building with straw encompasses far more than a new wall-building system, however, as the whole building is constructed of natural materials with very low embodied energy (the energy required to make the product) and a negative carbon footprint, all at an affordable price.

Straw is a flexible material and this requires us to work with it somewhat differently from how we would if it were rigid. Accurate measurement and precision is impossible and unnecessary with straw, but working without these aids can be worrying to the novice, and threatening if you're already used to twenty-first-century building techniques. It is very important to make this clear at the outset. You have to develop a feel for the straw. You have to give it time; absorb its flexibility. It is possible to be macho about it – to hurl bales around single-handedly and force them tightly into spaces, but this always has adverse consequences. Rushing the process, and working alone or competitively can mean that an adjoining section of wall is distorted and pushed out of shape – a section that someone else has spent time and care in getting right. Strawbale building is as much a personal learning process as it is about learning a new building technique. More than any other material (except perhaps cob and clay), it is susceptible to your own spirit and that of the team. It is not something to do alone. It requires cooperation, skill-sharing and common sense. Many of the inspirational and artistic features occur in this atmosphere. It is empowering, expanding the world of opportunities for you and making possible what you thought to be impossible!

Building with bales can be inspiring and transformative, and working together with a group of people to build your own home can be one of the most empowering experiences of your life.

The atmosphere and environment in which we live is a matter of increasing concern to homeowners and designers alike. There is a growing body of knowledge on the harmful effects of living long-term with modern materials that give off minute but significant amounts of toxins, the so-called 'sick building syndrome'. Living in a straw house protects you from all that. It is a natural, vapour-permeable material that has no harmful effects. Hay-fever sufferers are not affected by straw, as it does not contain pollens. Asthmatics too find a strawbale house a healthier environment in which to live. Combined with a sensible choice of natural plasters and paints, it can positively enhance your quality of life.

When building a house using bales of straw, many of the other elements of a conventional building remain. The installation of plumbing, electrics, interior carpentry, joinery and partition walls may be no different from the methods and materials you are used to, though of course they could also be re-thought in terms of using sustainable, locally sourced and recycled materials. This book covers the environmental attributes of straw, how to design an affordable house, the different types of foundation, how to build walls with straw and stabilise them, how to protect walls from the weather and make them durable, how straw performs with humidity and how strawbale buildings can easily meet Building Regulations requirements. There is also a section on frequently asked questions (Appendix 2), and a resources section which includes further reading, contacts and references to research (Appendix 3).

Building with bales can be inspiring and transformative, and working together with a group of people to build your own home can be one of the most empowering experiences of your life.

History

Strawbale buildings were first constructed in the USA in the late 1800s, when baling machines were invented. The white settlers on the plains of Nebraska were growing grain crops in an area without stone or timber with which to build, and while waiting for timber to arrive by wagon train the following spring, they built temporary houses out of what was, to them, a waste material – the baled-up straw stalks of the grain crop. They built directly with the bales as if they were giant building blocks, with the bales themselves forming the loadbearing structure. This is known as the Nebraskan or loadbearing style. The settlers discovered that these bale houses kept them warm throughout the very cold winter yet cool during the hot summer, with the additional soundproofing benefits of protection from the howling winds. Their positive experience of building and living in strawbale homes led to the building of permanent houses, some of which are still occupied dwellings today!

This early building method flourished until about 1940, when a combination of war and the rise in the popularity and use of cement led to its virtual extinction. Then, in the late 1970s, Judy Knox and Matts Myhrman, among other pioneers of the strawbale revival, rediscovered some of those early houses and set about refining the building method and passing on this knowledge to an eager audience of environmental enthusiasts. Through the green and permaculture movements the ideas spread very rapidly, with most of the new buildings being this self-build, Nebraska/loadbearing style (see page 26 for more details). Before long, new techniques were developed to improve the building method, and *The Last Straw* journal was founded in Arizona to disseminate ideas, promote good practice, and provide a forum within which owners and builders could network.

The first known straw building in the UK was built in 1994, and the first in Ireland in 1996. Today, thousands of new structures are being built annually all over the world. There are several hundred in the UK and possibly 50 in Ireland at the present time,

most with full planning permission and Building Regulation approval. Although the UK began building with straw bales earlier than any other European country except France, we have since fallen far behind in terms of official recognition and encouragement of this innovative and pioneering technique. However, the nature of straw is such that some pioneering individuals and institutions have taken the risk to prove just what straw can do. In Stansted Mountfitchet is a saleroom built for Sworders Ltd. It is a compressive frame style, and at 1,100m^2 is the largest strawbale building in the UK. It won the East of England RICS Sustainability Award and a Commendation in the International Awards in 2009, and was built for the very competitive price of £950/m^2.

In 2008, another innovative two-storey loadbearing strawbale house won the Grand Designs Eco-home of the Year Award. In 2009, North Kesteven Council in Lincolnshire became the first local authority to build semi-detached council houses out of straw.

Why use straw?

Sustainability

Straw is an annually renewable natural product, formed by photosynthesis, fuelled by the sun. Over 2 million tonnes are produced surplus to requirements each year in the UK. Using straw can mean less pressure to use other more environmentally damaging materials and, in the unlikely event that the building were no longer required, it could be composted afterwards. It is low in embodied energy and has a seriously negative carbon footprint, storing carbon in its fabric for the lifetime of the building.

Energy efficiency and greenhouse gas emissions

Over 50 per cent of global anthropogenic greenhouse gases are produced by the construction industry and the transportation associated with it. If the surplus straw in the UK was baled and used for local building, at least 420,000 houses could be built per year. That's almost half a million super-insulated homes, made with a material that takes in carbon dioxide and makes it into oxygen during its life cycle. Coupled with vastly reduced heating requirements, thereby further reducing carbon dioxide emissions from the burning of fossil fuels, **strawbale building can actually cause a net decrease in greenhouse gas emissions and hence have a negative carbon footprint**.
To improve the energy efficiency of houses is the design challenge of the twenty-first century. Strawbale building designs are extremely airtight, reaching Sustainable Homes Code 5 easily, and Code 6 by adding a green roof, solar panels, rainwater harvesting and heat exchangers.

Highly insulating

Straw provides super-insulation at an affordable cost. In walls typically over 450mm thick the U-value is **0.13W/m^{2}K**, two or three times lower (i.e. better) than contemporary materials, and much lower than current Building Regulations require (see Chapter 14). When used with a design with south-facing windows, to maximise solar gain, and clay or lime internal plasters, a

strawbale house stores latent heat, because it has high thermal mass even though it is not masonry. This means there are no sudden changes in temperature if you open the windows or doors occasionally, as can happen in houses that have only insulation but low thermal mass.

Acoustically insulating

Strawbale walls are also super-insulative acoustically. There are two recording studios in the USA built of straw bales for their soundproofing quality and insulation, as well as one in Wales, the Strawdio. Strawbale wall systems are increasingly being used near airport runways and motorways as sound barriers in the USA and Europe. Amazonails is pioneering the use of loadbearing strawbale party walls as thermal and acoustic barriers for semi-detached houses.

Low fire risk

Plastered strawbale walls are less of a fire risk than traditional timber-framed walls. (See Appendix 2, Frequently asked questions.) Research in the USA and Mexico has shown that "a straw bale infill wall assembly is a far greater fire resistive assembly than a wood frame wall assembly using the same finishes."*

Affordable

Straw is currently produced surplus to requirements and a construction-grade bale costs about £2.50 delivered or 80p from the field. The walls of a three-bedroomed, two-storey house can be built with 350 bales. Also, because the building method is so straightforward, people without previous building experience can participate in the design and construction, thereby saving on labour costs.

The most significant saving on strawbale houses is in the long-term fuel reductions owing to the high level of insulation. Heating costs can be reduced by up to 75 per cent annually compared with conventional-style housing, and the savings therefore continue to accrue throughout the life of the building.

If the surplus straw in the UK was baled and used for local building, at least 430,000 houses could be built per year. That's almost half a million super-insulated homes with a negative carbon footprint.

Structurally sound

Bales of straw are more than adequate to carry typical loadings of floors, roofs and winter snow. They have passed loadbearing tests both in the laboratory and in practice, and are used to build houses of at least two storeys. Imagine placing a new sheaf of photocopy paper on the floor and then standing on it. It squashes down with your weight. Now ask two or three friends to stand on it with you – it doesn't squash down any more than it already has done. This is what straw does. We know how much a densely packed construction-grade bale will compress under load, and once we've made

* 1996 Report to the Construction Industries Division by Manuel A. Fernandez, State Architect and head of Permitting and Plan Approval, CID, State of New Mexico, USA.

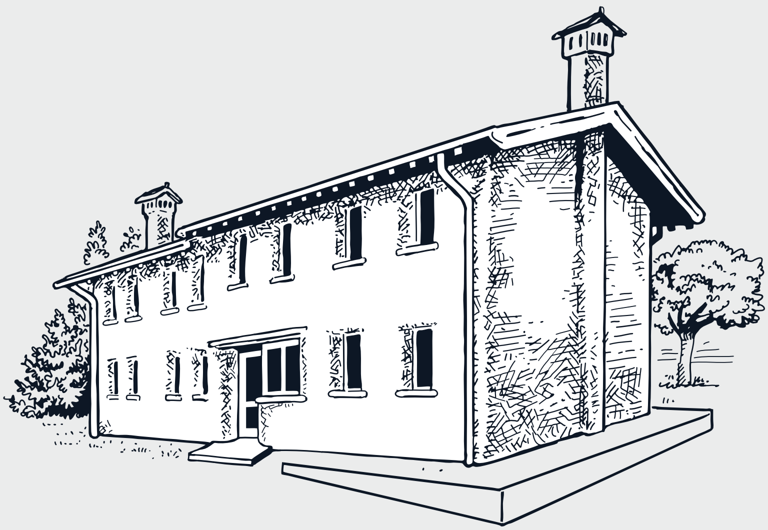
it do this, it won't compress any more. Alternatively, in timber frame methods (see Chapter 3) bales are not used structurally; they simply infill the gaps between posts, and it is the posts that carry the load (and take away an engineer's anxiety). The bales do not take weight, although they could!

A healthy living environment

Straw, particularly organic straw, is a healthy alternative to modern materials. It is natural and harmless. It does not cause hay fever since it's not hay (i.e. it doesn't contain pollen), and in fact it is the building material of choice for many allergy sufferers because it is so innocuous. Living within straw walls can enhance the quality of air we breathe, because it does not give off harmful fumes such as formaldehydes or dioxins, as many modern materials do, and because it is a vapour-permeable material, thereby helping to keep the inside air fresh. Coupled with the use of non-toxic organic finishes such as clay and natural pigments and paints, it can provide one of the safest and most comfortable atmospheres in which to live. Another health benefit is the ambience inside a strawbale house, which is calm, cosy and peaceful. This is partly to do with the high level of sound insulation, partly to do with the air quality, and partly to do with the organic feel to the house – a beautiful, nurturing and safe environment to inhabit. Try it!

Empowering and fun!

The most unquantifiable aspect of a strawbale house has to be the way that the building process itself empowers ordinary people. It is accessible to many people who are otherwise excluded from the design-and-build process, and enables them to transform their living environment, and their lives, in a very enjoyable way. Even mainstream builders, who are some of the most sceptical people when faced with a new material, are transformed by working with straw, and become firm believers in its qualities and performance.



Chapter 2

AFFORDABLE HOUSES WITH LOW ENVIRONMENTAL IMPACT

Quality and affordability

The environment we live in affects our moods and the way we feel. It can make us feel confident, optimistic and motivated or demoralised, downtrodden and hopeless. When buying a house, the question 'What would I feel like if I lived in this house?' isn't usually the first one we ask – it's more likely to be 'Can I afford it?' We don't ask whether the house will help us to grow, to be purposeful, to contribute to society, or whether it will make us feel small and mean. Imagine what our world would feel like if our homes were full of positive, optimistic and creative energy! Although we have the power to change things, and the ability to make choices, these can often feel severely limited by a culture dominated by financial imperatives rather than principles of well-being or contentment. It can be hard to envision a world for ourselves that nurtures and sustains us. But why should we accept anything less?

Feeling good is vitally important to well-being, but it is not taken into account within construction. If we build homes that people love then the people who inhabit them will want to look after them and preserve them. How things are built, the energy and the intention with which they are built, becomes part of the fabric of that building. The way our construction industry operates does not take feelings and processes into account, which have an impact on quality; it values only function and economics. The system of piecework on building sites, where workers are paid by the number of jobs they complete, or the use of subcontractors who submit low quotes just to win contracts, encourages poor-quality work as each tries to work faster and cuts corners to earn more money. Competitive tendering has the same effect: companies are encouraged to submit the lowest price possible in order to win a contract, and then have to build as fast as possible with the cheapest materials in order to stay within the quoted price. Manual skills are not valued, training is not taken seriously, and the industry is not proud of itself.

Building cheaply does not benefit any of us in the long run, but we have been forced into a narrow view of choice, where our own well-being is secondary to financial implications. Choices are restricted by the limited range of what's on offer. Short-term savings cost us more in the end, because mediocre building makes us all unhappy and dissatisfied, and unhappy people can be disruptive

for the rest of society – plus the buildings themselves are not durable. We are making do with what's available when we could be creating places to live and work that actually increase our sense of belonging in the world; that give us a centred space to begin from each day and return to at night.

This limited perception of choice, between affordability and quality, is flawed. It is absolutely possible to incorporate a more positive value system into the construction industry and still build affordable houses, as is being proved through the development of strawbale and natural house building. Affordable houses are now being built, to very high standards of thermal efficiency, without compromising on quality and while providing a beautiful, organic ambience to the house that increases well-being.

It is absolutely possible to incorporate a more positive value system into the construction industry and still build affordable houses, as is being proved through the development of strawbale and natural house building.

It is now possible to build a thermally efficient three-bedroomed strawbale house for £100,000, with the involvement of people who will live in and around it, which will last upwards of 200 years – and this price will drop as more are built. This cost is for a house built by a contractor; if you do some of it yourself or with friends, and run courses to teach people the skills at the same time as building, then you can make further savings. This is on top of the long-term savings to be made on heating bills, as described in Chapter 1. In fact, with good design, it's possible to build a strawbale house that has no or almost no need for heating. In years to come this will be an increasingly desirable feature that will make your strawbale home more attractive to buy than similar houses in the same area.

In mainstream construction, it's possible to build a modern brick-and-block house for £700-850/m^2 (£65-80/ft^2), giving a price of £70,000-85,000 for a three-bedroomed house. However, it is not fair to compare such a house with the strawbale houses currently being built, in terms of thermal efficiency, comfort and durability – we have to compare like with like. In order to build a modern house that matched the insulation values and quality of a strawbale house, the price would increase well beyond the £100,000 mark. This is why the construction industry is complaining that government targets for affordable but sustainable houses are not achievable, and they *aren't* achievable by using current mainstream materials. We need a radical change!

Designs for such houses have been developed over the last few years by amazonails, incorporating the features described below. The first house to be built like this is at Ralegh's Cross Inn in Exmoor: a two-storey, semi-detached, loadbearing strawbale house for hotel staff. North Kesteven Council in Lincolnshire is the first local authority to build social housing out of straw: this is another two-storey, semi-detached, loadbearing straw building comprising two three-bedroomed semis. These buildings are leading the way in bringing the cost of desirable home ownership within the reach of the ordinary person again.

Keeping costs down

If we are to accept the challenge of building affordable homes then we have to radically rethink the way we build, and using the current cavity-wall system is not the way to go: it's a really bad design that has never worked well in practice, and the materials used to construct it are not sustainable. Tinkering about with this system can bring only minor changes in cost, and won't give us the thermal efficiency that we need for the twenty-first century – and that's without taking into consideration the feel of the homes inside. At the moment, the construction industry seems to be content to rely on outdated systems and add-ons and still fails to meet government targets. We need a complete rethink of how we build houses. We have to be more creative!

An affordable house is achieved by a combination of factors, described below.

Simplicity of design

The more you add quirky little bits to your building – unusual shapes, different levels of roof pitch, even curves; in fact most things that make your house really quite an individual home – the price will go up if you're having it built for you or buying it off the peg, because all these things take extra time or extra materials. It's a shame, but it's true that a basic box is cheaper to build than a beautiful circular house. This is partly to do with the fact that modern building materials come in basic box-sized shapes, so when you try to make them into curves there is a lot of wastage. It's true that the standardisation of materials has come about as a result of trying to make the construction process cheaper, but with that impetus we've also lost the ability to make our homes individual and beautiful and truly ours.

Often the simplest houses are the most beautiful. Look at a typical cob (earth-walled) long-house: thick walls, rectangular structure, with proportions that resonate subconsciously in the human psyche, reflecting the geometry found everywhere in the natural world – the reason why some buildings are more pleasing to us than others. These houses sell at a premium, they last upwards of 400 years, they have an organic feel to them and they have a quality of atmosphere that is hard to describe but feels safe, cosy and pleasing. They were built by lots of people coming together to help, with natural materials, and to designs that were tried and tested. In fact, they sound very similar to modern strawbale houses! We can keep costs down by designing houses that are simple to build from a practical point of view, are made of readily available and common materials, use accessible construction methods, and have an internal design that's well-thought-out and relevant to modern lifestyles – such as being open plan so that heat can circulate easily around the house.

Local and natural materials with low embodied energy

Another way to keep building costs down is to use materials that don't cost the Earth. The more highly processed a material is and the further it has to travel to your building site, the more it will cost, both environmentally and financially. The closer it remains to its natural state, the cheaper (and healthier) it will be. In one sense building a strawbale

house may only mean changing the wall system from a typical brick-and-block cavity to using straw, but why stop there? Eighty-five per cent of the materials in a typical amazonails-designed strawbale house are natural, with low embodied energy. These buildings use no cement at all, not even in the foundations, require no plastic damp-proof courses, and use sheepswool, hemp and wood fibre, lime and clay, and durable and small-dimension timber.

If you compare the embodied energy (measured in kWh/m^2) of 1m^2 of a standard amazonails straw wall (loadbearing straw bales rendered externally with lime and plastered internally with clay) with that of 1m^2 of a standard modern wall (brick, lightweight block, mineral fibre insulation, gypsum plaster) of approximately equal super-insulation (to make the comparison of like with like), the results are as follows. (From the MSc thesis of Carol Atkinson, who has built her own mobile strawbale holiday home at Howden, East Yorkshire, on which she carried out extensive research.*)

1m^2 of standard strawbale wall	36.5kWh/m^2
1m^2 of cavity wall insulated with mineral-fibre insulation	172kWh/m^2

Clearly there is no comparison! These results are so good that at the moment, most people working in the construction industry are not able to accept them (it's a bit like talking a foreign language – it's so different, it doesn't make sense at first).

Accessible building methods

Another way of keeping building costs down is to help with the building yourself, and get your friends and family to join in. This is possible with strawbale building because the methods of construction are simple and straightforward, and there are no hidden technologies. And the money saved on the labour costs will mean you can afford to be more creative with your design choices.

You can help with the building yourself, and get your friends and family to join in. Strawbale building methods of construction are simple and straightforward, and there are no hidden technologies.

Many self-builders have been able to afford 'designer'-type houses, because they have put in their own time and effort over a number of years, worked more slowly with volunteers and by running courses, and taken time to find reusable and recycled materials. Increasingly, we are pioneering this process on mainstream construction sites as well, working with main contractors and running courses on-site for the public, the builders and the intended users of the building. Working with large straw blocks to put up walls with your friends is fast, effective and fun! There are very few people who are not able to build using straw, and strawbale building sites commonly include younger and older people, and people with a diversity of talent and experience. This alternative approach to building has the

* Carol Atkinson's strawbale cabin is available for let, and you can find a copy of her thesis, *Energy Assessment of a Straw Bale Building*, on her website www.homegrownhome.co.uk. The cabin is pictured in the colour section of this book.

long-term benefit that people feel happier if they are involved in their own building; they feel a sense of ownership and identify with it.

Open accounting systems and partnership working

Whatever happened to trust? Being worried and fearful about finances and the integrity of your colleagues can completely destroy trust. We live in a culture of fear rather than trust; we're encouraged to expect the worst rather than the best, to insure against our fears and generally protect ourselves just in case; inhabiting a more and more frightened and insular world. We need to learn how to rely on ourselves and our friends again, to build networks and support each other. A system built on fear and self-interest is bound to topple in the end because greed demands that there is always more to be had. The essence of sustainability is to use what is enough, and no more. We need to learn to be satisfied with what we have, to recognise worth when we find it, and to stop trying to get more and more and more! This is not life-enhancing.

We need to be able to trust our builders, and they need to convince us that they will work hard, uphold high standards of quality and work, and can be left alone in our homes without our worrying about safety. The industry needs to be able to trust the client, to know that we are willing to pay a fair price for a job well done, and that we will be honest and just in our dealings with those we contract. If this atmosphere of trust existed then we could also have a reasonable discussion about accounting; about how much things cost, what is a fair price for the job, and sharing the profit if all goes really well (or the loss if something goes wrong). There would be no need for competitive tendering, and all its associated costs – work could be shared around with a price agreed at commencement.

If we are able to communicate well, speak with clarity and listen attentively; if we can bring honesty and integrity to the discussion table; if we're willing to trust each other, take risks, work together and learn from mistakes, then we are opening up the boundaries of possibility. If we believe that we all want to create the best building possible, and that different perspectives can actually help achieve this, then working in partnership has got to be the way forward. The more you believe in somebody the more they excel. The feeling of all being in this together, working for a common aim, is a feature of many strawbale builds. There are many ways in which we find we are interdependent and need to rely on each other. It focuses the mind and allows for innovation.

Is there enough straw?

If we were to build all the houses we are told we need each year, would there be enough straw, and would we have to use more land to produce it? The table opposite shows recent wheat-straw production in England, and its uses.

Even in a bad year, when there was a lot of rain that ruined the harvest, we still produced 2.37 million tonnes of straw that had no

	Wheat straw (million tonnes)					All cereals (million tonnes)	
	Area (hectares)	Total	Ploughed back in (40%)	Baled for farm use (30%)	Baled for sale (30%)	Area (hectares)	Total
2007	1,690,984	5.92	2.37	1.78	1.78	2,393,073	8.38
2006	1,709,042	5.98	2.39	1.79	1.79	2,387,691	8.36
2005	1,748,414	6.12	2.45	1.84	1.84	2,429,363	8.50
2004	1,865,163	6.53	2.61	1.96	1.96	2,609,459	9.13
2003	1,726,563	6.04	2.42	1.81	1.81	2,543,048	8.90

Source: Defra 2007

other use than to be ploughed back in. If a standard three-bedroomed house takes 350 bales to build, then this amount of straw can build approximately 423,000 houses. So clearly the answer is yes, there's more than enough straw, and no, we wouldn't have to use more land to produce it, we'd just have to stop ploughing some of it in. This practice began after the law changed and surplus straw could no longer be burnt.

Straw houses and carbon footprint

The Carbon Trust defines a carbon footprint as 'the total set of greenhouse gas emissions caused directly and indirectly by an [individual, event, organisation, product], expressed as CO_2e [carbon dioxide equivalent].'

Almost all houses have a positive carbon footprint because of the materials they are built with. If you took all the materials used in their construction into account and analysed how much CO_2 was produced or sequestered (stored) by them inherently, or produced during their manufacturing process by the use of energy that emitted CO_2, or produced as a result of transportation associated with them, it would show that they are responsible for the release of far more CO_2 into the atmosphere than any that they might store. The government is encouraging the construction industry to achieve a zero carbon footprint, but we can achieve a resoundingly negative footprint very easily by using a completely different approach to building walls.

Houses built of naturally grown materials, e.g. straw, wood, hemp, newspaper (for insulation), etc., are totally different because

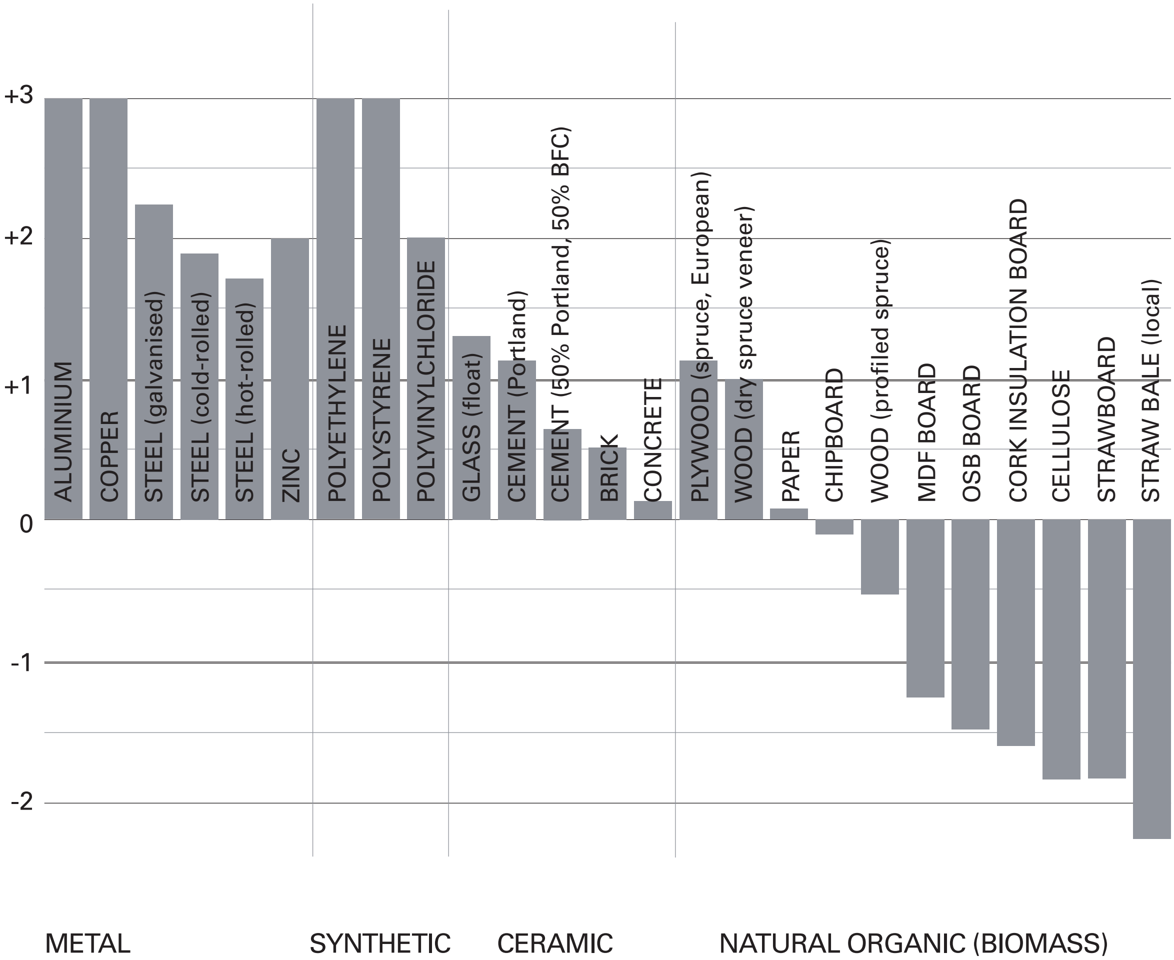
they are made up of materials that have been grown in the earth, and as all plants take in CO_2 from the atmosphere and release oxygen, they all store CO_2 and have a negative carbon footprint by their very nature.

The figure opposite shows 25 common materials and their CO_2 pollution. You'll see that the worst polluters are the metals, because they take an enormous amount of energy to extract from the earth. Fortunately, we use them in only small quantities, so their contribution to our carbon footprint is minimal. Cement, on the other hand, seems fairly average and on a par with plywood, until we realise just how much of this material we use. Next to water and sand it is the most-used commodity globally, so it becomes probably the single most damaging polluter in the world. If you look at where cement factories are situated – right next to electricity-generating plants – this gives you a clue as to just how much electricity is used to make it. They would put too much strain on our system if they were further away! **Most of the plant materials, on the other hand, are non-polluters except for the highly processed ones.**

According to Carol Atkinson, the average UK home produces 50 tonnes of CO_2 during its construction. In contrast, research by Jakub Wihan, in his thesis *Humidity in Straw Bale Walls and its Effect on the Decomposition of Straw* (see Appendix 1 for more on this subject) shows that one 16kg straw bale stores 32kg of CO_2. Since it takes about 350 bales to build a typical

This three-bedroomed strawbale house, built in 2000, will lock up carbon for the lifetime of the building –– expected to be at least 200 years. *Photograph © Bee Rowan*

Net CO_2 pollution (kg) emitted by production of
1kg of 25 common building materials



Source: Wihan, J. (2007) *Humidity in Straw Bale Walls and its Effect on the Decomposition of Straw**

* MSc Architecture thesis written for the University of East London. Available at www.jakubwihan.com/pdf/thesis.pdf.

three-bedroomed house, this type of building will store roughly 11.2 tonnes of CO_2 in its fabric.

In addition to using plant materials to build with, using materials with low embodied energy also reduces the building's carbon footprint. The table below shows the embodied energy of all materials used in a typical strawbale house, and the percentage volume of these materials in relation to the whole.

This shows very clearly that almost 85 per cent of a typical strawbale house is made of materials with low embodied energy – in contrast to a masonry house, which uses roughly 85 per cent high-embodied-energy materials.

Embodied energy	Materials	Percentage volume of all materials
Extremely high	Plastic straps, lead flashing, hinges, locks, handles, nails and screws, galvanised downpipe	0.14%
Very high	Double glazing	0.09%
High	OSB, external plywood, Tyvek membrane	2.19%
Medium	Baler twine, floorboards, wooden gutters, cork underlay, celenit fibreboard, door/window frames, lime plaster, hessian	7.34%
Low	Local timber	5.28%
Very low	Straw bales, sheepswool insulation, hazel, clay plaster, cedar shingles	84.95%

Source: Atkinson, C. (2008) *Energy Assessment of a Straw Bale Building**

* MSc Architecture thesis written for the University of East London. Available at www.homegrownhome.co.uk.

The way forward

The design of affordable houses is still under development, but amazonails is already building houses and other types of building with mainstream contractors at competitive prices. These prices will come down further as techniques are refined. Strawbale building in the UK has reached this point in only 15 years, with no government funding or financial backing from investors, which is a remarkable achievement and testament to its firm grounding in grassroots common sense, providing what ordinary people genuinely want. In this time, several unique individuals have built their own houses, keeping costs down by using their own and volunteer labour, running courses and reusing materials. Norita Clesham's spiral house in Ireland cost her £70,000. Ben Law's house in the woods cost him only £28,000. Rachel Shiamh's house, which won the Grand Designs Eco-home of the Year in 2008, cost her £70,000.

The construction industry needs radical change if we are to bring the cost of homes back to a level that ordinary people feel they can afford without being in debt all their lives. This means a complete rethink of what we build houses from – going back to less-processed and local materials – and of the process of building itself – making it possible for people to participate in building their own homes in some way, as self-builders or through housing associations and partnerships with contractors. This is all possible!

Ben Law built his house of coppiced timber with infilled straw bales at a really low cost to a Grand Design. *Photograph © Barbara Jones*

Chapter 3

STRAWBALE BUILDING TECHNIQUES EXPLAINED

Loadbearing (also called Nebraska)

This is the original way of building with straw bales, pioneered by Nebraskan settlers in the USA in the late 1800s. At amazonails, we prefer this method above all others for building any type of construction, small or large, because of its simplicity, flexibility of design, enhanced thermal performance and cost-effectiveness. The potential for empowerment through working together on a shared project is one of the great advantages of this type of building, as it is such an accessible building method: pretty much anyone can do it, and it's a lot of fun!

In the loadbearing technique the bales, which are structural blocks, are designed to take the weight of the roof; there is no need for any other structural framework. They are placed together like giant bricks, pinned to the baseplate (a continuous timber plate, usually a flat ladder structure, that sits on top of continuous-type foundations) and to each other with coppiced hazel, and a continuous rigid timber ring beam on top spreads the floor and/or roof loads across the width of the wall. For two-storey houses, the floor joists at first-floor level are attached to the ring beam before building up the straw walls again beneath the roof. The wallplate, or roofplate (a continuous perimeter plate that sits on top of the walls at each floor level and under the roof) is fastened to the bales with coppiced hazel and may be strapped down to the foundations, depending on local weather conditions and the weight of the roof. The roof is constructed on top of the roofplate, following strawbale design principles.

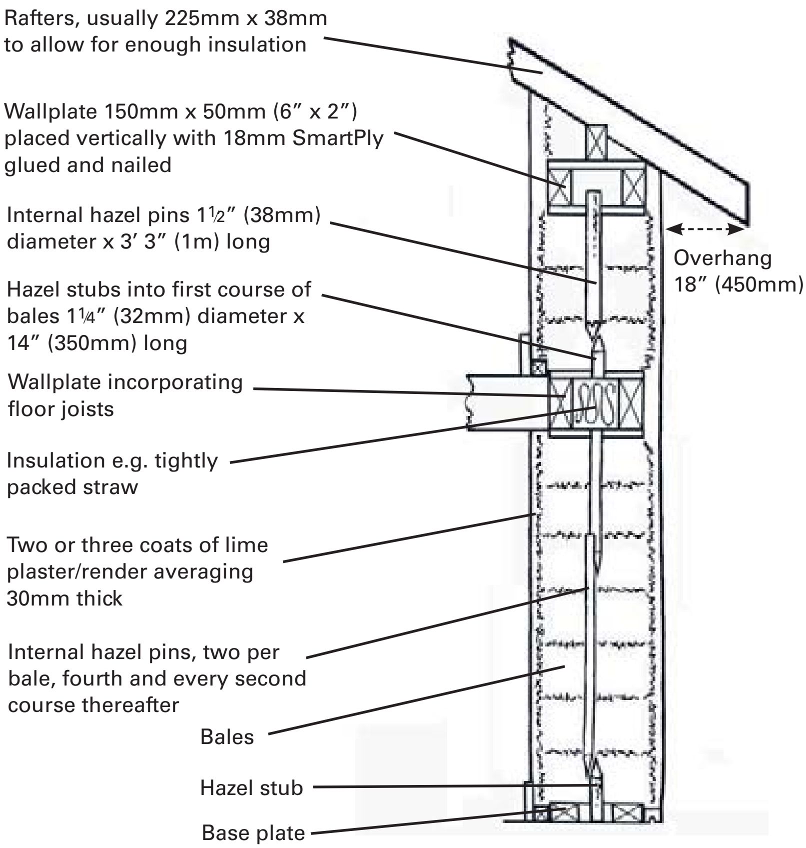
Windows and doors can be installed in various different ways. The simplest method is to place them inside structural box frames, which are built into the bales as the walls go up. This approach is usually used for small-scale and community buildings and self-build experiments. It may require more timber than other methods, but it keeps the actual bale building aspect to its simplest. It requires little previous knowledge of wall construction and is very accessible.

An alternative way of installing windows and doors, and one used predominantly on mainstream building sites, is to use doubled-up 100mm x 50mm (4” x 2”) uprights either side of the opening, fastened securely to the baseplate and projecting through slots in the roofplate. These are housed fully into the

bale either side and the window or door is fixed to them.

The loadbearing style is a simple, straightforward building method, easy for non-professionals to design following readily comprehensible basic principles. Designs from one-room to two-storey homes can be created using a simple step-by-step approach. Curves and circles are easy to achieve, though at some extra cost due to more complicated timber work. And as the straw is very forgiving, total accuracy in plumb is not necessary, but wilder variations can be brought back into shape easily! Self-builders love it because it's fast, fun and fulfilling! Most of the larger loadbearing buildings now being built in the UK and Ireland are actually pre-compressive loadbearing designs (see page 32).

SECTION THROUGH LOADBEARING STRAW WALL



Loadbearing in a wet climate

Over the years, the main disadvantage of the loadbearing technique – namely how to keep the straw dry throughout the whole building process despite the sometimes prolonged wet weather of the UK and Ireland – has been dealt with. Ways we can address this issue are as follows.

- Prepare everything in advance (prefabrication) so the whole building goes together quickly once you start, like building with Lego. The vulnerable time of exposure to the weather, and the need to keep it covered with tarpaulins, can be reduced to a few weeks.
- For small buildings, build underneath a marquee or large tent.
- For larger buildings, increase the height of the scaffolding (needed to build the walls and roof), add a temporary roof over the top, and cover in the sides. This level of protection is required for the lime render anyway, so it can be cost-effective to protect the whole building, ensuring there will be no time lost due to the weather for any aspect of the building, not just the straw, at any stage.
- Use an impressive-compressive method (see pages 31-34) and use the floor or roof as the main weather protection.

Loadbearing for warehouses and retail units

Large open spaces can be built very quickly and effectively using mini Heston or Quad bales. At around 8′ long and 2′ high per bale you can appreciate how quickly a person with a forklift truck and telehandler machine can build a new DIY superstore. Obviously there's a little bit more complexity to the design than this, but you get the picture!

Basically there is no real limit to design or size when using loadbearing techniques. We have built circular and curvaceous buildings, and detached and semi-detached two-storey buildings using this method. It's all about understanding the material and having a creative approach to problem-solving.

Infill (also called post and beam or timber frame)

Next to loadbearing, this is the other 'traditional' way of building with straw. It was developed in the USA in the late 1970s, as their construction industry was familiar with it as a practice. In this method, the weight of the roof is carried by a timber, steel or concrete framework; the bales are simply infill insulation blocks between the posts, and a key for plaster; they are not used structurally. You might make this choice because you like the look of timber and you want to use its beauty in your design, or because you are going for something really ambitious with large openings and spans, and a loadbearing building just won't do it. This method also has the advantage of giving peace of mind to clients and those professionals (architects, engineers and building inspectors) who aren't quite ready to accept just what straw can do as a building material. It is often the preferred option for architects, as the structural concepts are not innovative and rely on an already-

established method of building, therefore the risk associated with an experimental technique is minimised. There is no need to satisfy oneself of the capacity of the bales to take the roof weight, since the framework does this. This method requires a high level of carpentry skill and uses more timber than a loadbearing design, so has cost and environmental implications.

When designing a timber framework to have straw as an infill material it is really sensible to have somebody who understands how straw works to work with the framework designer; this means that all sorts of practical difficulties can be eliminated before you ever get on site. This type of building needs to be designed with the dimensions and properties of the bale as the first consideration, but what usually happens is that the building is designed as per standard framework techniques, and the bales have to somehow fit within that. Because of the nature of the straw, it is possible to solve most practical problems on site, but doing so can detract from the ease of build and the fun – if, for example, you're having to make little parcels of straw, or sew packets on to the front of posts and so on just to get around the fact that the frame wasn't designed with the straw in mind.

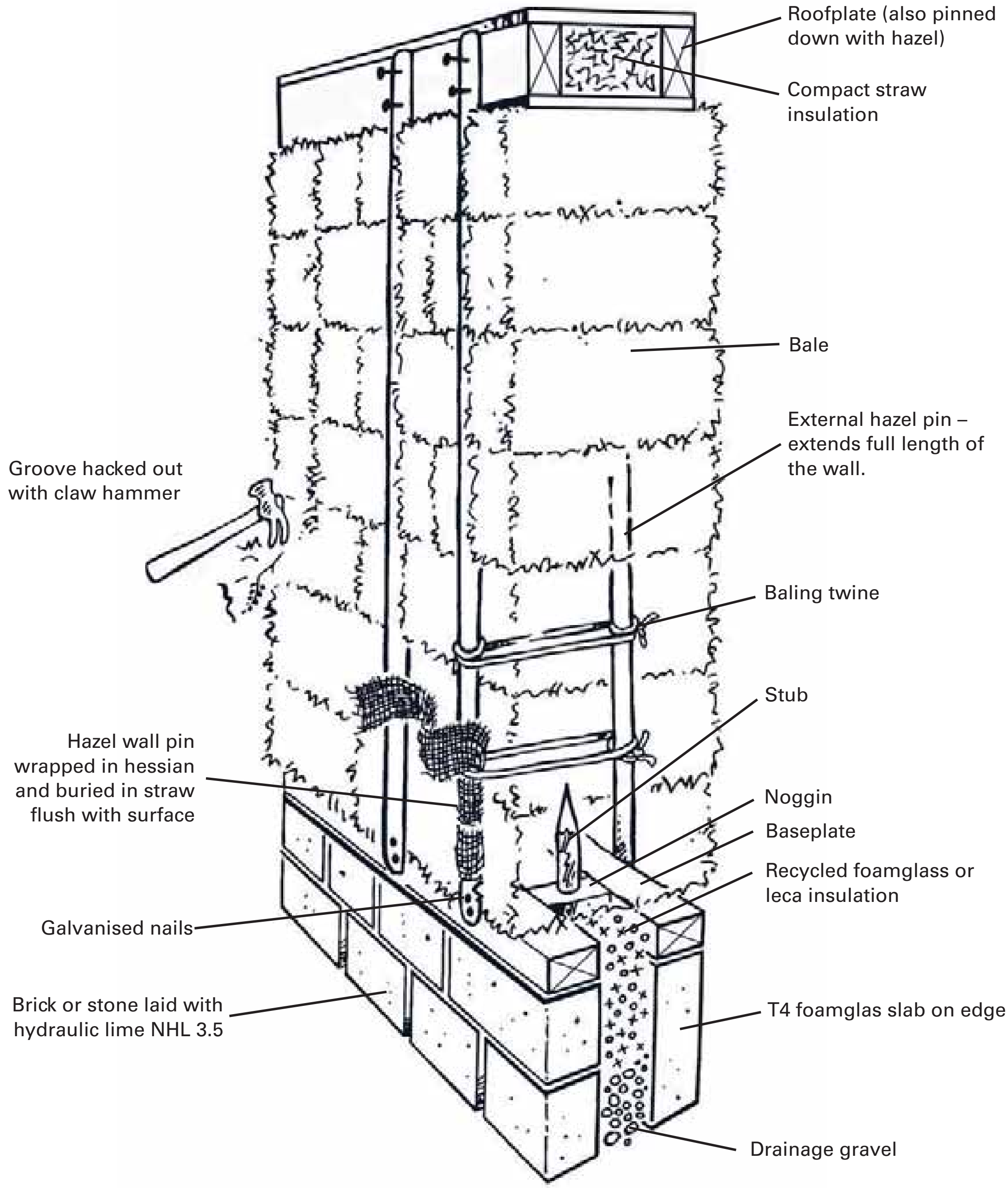
The main issue with this type of building is stabilising the straw ready for plastering. Traditionally, this would have been done by using external pins, fastened to the baseplate and wallplate inside and outside the wall. These long pins would be sewn together with baling twine through the body of the bale using about two stitches per bale: as you can appreciate, this is an enormous amount of work. Because this adds time and expense to the job, other methods of stabilising the straw have been devised – see 'Compressive frame technique', page 33.

One major drawback to the infill method is that if the posts are quite large, 200mm x 200mm (8″ x 8″), fitting the bales around them can be difficult, and the ideal location for them is to protrude into the building – but if you do this, then there is not much post to push against sideways when the bales are being installed. Also, if the posts are located on the inside of the building, and the bales are essentially wrapped around the outside edge, then we have the problem again of how to stabilise the straw with no beam above it. Tricky! This type of design usually results in a lot more timber than would have been necessary for a standard timber frame building, simply because the straw itself hasn't been taken into account properly in the design, so more timber is required as a plate below the straw and to cover the top of the straw to make a connection with the framework.

From a design point of view it is much better to use small-dimension timber buried in the centre of the bales. This makes stabilising the straw more efficient, and it also means that there's no possibility of air leakage around posts, as there is not a flat join between straw and timber, but obviously then you don't get the benefit of seeing the timber as part of the design.

On the plus side, all of the timber work can be prefabricated and brought to the site for assembly, which will help keep costs down, and very large open spaces can be created using specially designed roof trusses that sit on the posts. However, these advantages can also be incorporated into compressive frame techniques (see page 33).

LIGHTWEIGHT FRAME WALL



Impressive-compressive methods

As strawbale building has become more professional, ways have been developed of speeding up and improving techniques to make them more appropriate for the modern building site. The following principles can be applied equally to loadbearing and infill methods.

Traditionally, in loadbearing buildings the roof weight would compress the bales over a period of about six weeks, but by pre-compressing the straw, settlement caused by the roof and floor loads can be controlled and encouraged to happen much more quickly. Now that straw is becoming a mainstream building material it is necessary to be able to construct loadbearing buildings fast and simply using pre-compression. Various methods of pre-compressing straw walls have been used around the world since at least 1994. The idea is to force settlement of the bales and maintain the pressure by the use of tie-down straps, fastened over the top of the wall and down to the foundations. When you see this happen, it transforms a very flexible wall into a solid, strong, extremely *impressive* structure in a few moments! (No-nonsense builders, previously sceptical of this new-fangled building material, have become instant advocates at this point in the build and have been found showing their friends round and boasting about their building's credentials.) Methods include rubber tubes placed on top of the walls, fastened down with chains and then filled with air (first used in Canada), industrial-strength ratchet straps, placed over the top of the walls and fastened to the foundations, and then ratcheted down tight (as used in California) or pairs of threaded rod attached to the top and base plates and screwed down (used in Australia).

You can appreciate that putting the walls under the amount of pressure required to compress the bales, particularly when using construction-grade bales of very high density, requires a lot of force. This means that whatever you fasten the ratchet straps to at foundation level needs to be very strong. For commercial house building, this is a design detail that needs to be added in at the earliest stages. The following are two ways in which it can be done.

- Lay a 25mm (1″) water pipe through the foundations so that when you are ready you can insert a metal pin, about 18mm (¾″) diameter, through it, which projects about 100mm (4″) beyond each face of the wall. Ratchet straps can then hook on either side of the wall to this pin, the pin can be removed later, and the hole it leaves then pointed up.

- Extend the width of the baseplate, normally the width of a bale, by 50mm (2″) and project it to the inside of the building, so that you have a 50mm lip of timber that can be caught by the hook of the ratchet. On the outside face of the timber baseplate fix a temporary 50mm x 50mm batten: this will perform the same function and can be removed before plastering. This method can be used only if the baseplate is securely fastened down to the foundations, or if the weight of the walls above is sufficient to prevent the baseplate from lifting under the pressure.

Pre-compressive loadbearing technique

Buildings need to be carefully designed so that the principles outlined below work in practice. These techniques will generally be used for a commercial build, but for smaller or self-build types of building you may find them unnecessary. It's still perfectly feasible to allow the floor and roof weight to compress the walls without using pre-compression. All loadbearing designs are compressive, it's just a matter of whether you let the building structure itself compress the bales, or whether you help it along so you can build faster. Whichever method you choose, it is best that as much as possible of the timber work of the building is prefabricated, because this speeds up the actual time of the build and therefore its vulnerability to the weather. The baseplate, first-floor ring beam and joists, roofplate and roof can all be done in advance.

Using a crane and temporary props

Prefabricated parts can either be made off-site and brought to the site later, or constructed on-site next to the building. Either method has the tremendous advantage of enabling the roof to be built at ground level, thus saving on labour, time and scaffolding costs. The roof is not completed at this stage, so as not to be too heavy, only finished up to the vapour-permeable (weatherproof) layer. A crane is used to lift the first floor, and temporary timber columns and beams are placed beneath it for support, leaving enough room to install the straw underneath. The floor will need a temporary stem wall to be built centrally along its length to create a pitch for heavy-duty tarpaulins that waterproof the floor and cover in the sides of the building to give the straw protection from driving rain. The scaffolding should be sheeted on the outside for the same reason. The straw is now installed and the columns and beams are removed by raising the floor with acro props and taking the timber columns out, leaving the floor resting on the walls, which are then compressed by the weight of the floor itself; and by ratchet straps that go through the floor. The weight of the floor itself and the walls and roof above are usually enough to stabilise the building without the need for permanent tie-downs (these would be needed at this level only if this was a single-storey building with a lightweight roof, or there were severe winds). Once the ground-floor walls are complete, the roofplate and roof are lifted up above the first floor, on to more columns and beams, and temporarily held in place while the first-floor walls are constructed. At this stage, the roof provides waterproof covering over the building and tarpaulins or sheeted scaffolding protect the sides from driving rain. Again, the walls are compressed using ratchet straps over the roofplate.

Using scaffolding

An alternative to using temporary props is to build the scaffolding up to just above ground-floor height and use scaffold trusses across from one side to the other. The floor can then be lowered on to these and waterproofed while the straw is installed. When all the straw is in place, the floor can be lifted up, the trusses removed, the floor lowered on to the straw, and the trusses moved up the scaffolding to their next position, just above the height of the first floor

walls, where they will hold the roof until it is also ready to be lowered. This method was being pioneered on the North Kesteven building site in 2009.

Using props without a crane

An alternative to using a crane for lifting whole sections of the building is to construct the first floor directly on top of the temporary columns and beams, weatherproof it, then install the straw below and remove the props as described above. The first-floor walls and roof are constructed in the same way.

The timber used for the props is designed so that it can have a second use as part of the building later on. There has to be some flexibility in the building schedule to make sure that certain critical points of the build take place during dry weather, e.g. putting the roof on, as this obviously requires the straw walls to be uncovered, but these stages should not require more than one or two days to complete. We have used this method to build a two-storey semi-detached house and it worked extremely well.

Compressive frame technique

The two main drawbacks to the infill method of strawbale building, described earlier, are the difficulty of stabilising the straw enough for plastering and the extra cost associated with using a secondary frame of timber as well as the potentially structural straw. The compressive frame method addresses both these problems by making a framework building as much like a loadbearing one as possible – although for this reason it's often more sensible just to stick with true load-bearing! The basic idea of this compressive frame method is the same as for the compressive loadbearing method: that is, using various means to hold the floors and roof out of the way while the straw is installed, dropping these elements down on to the walls and then pre-compressing the walls beneath them. In framework techniques the floors and roof are held up by posts that remain a permanent part of the building, rather than by temporary props.

The basic principle is to design a frame with the floors and roof about 100mm (4") higher than their finished level, held out of the way by various means, and then, once the straw has been installed, to lower the floor and/or roof on to the walls, often using their weight to stabilise the straw without the need for pre-compression straps. This gives a covered space inside the building in which to store straw, but still means the sides of the building need to be protected from rain.

There are many different ways this can be done, and you can be sure that your engineer can think of very complex ones! It should, however, be kept as simple as possible, and can be done using folding wedges of timber and mortice and tenon joints, or threaded rod of some description, metal shoes for the posts, etc. If you do end up with lots of metal in the walls (which is expensive), the straw will need to be protected from its coldness by wrapping the metal in hessian or something similar, because cold metal could cause warm moist air to condense on to it, thus causing potential damp problems. With larger frames, the straw can be pre-compressed between each post, tightly packing straw between the top of the last

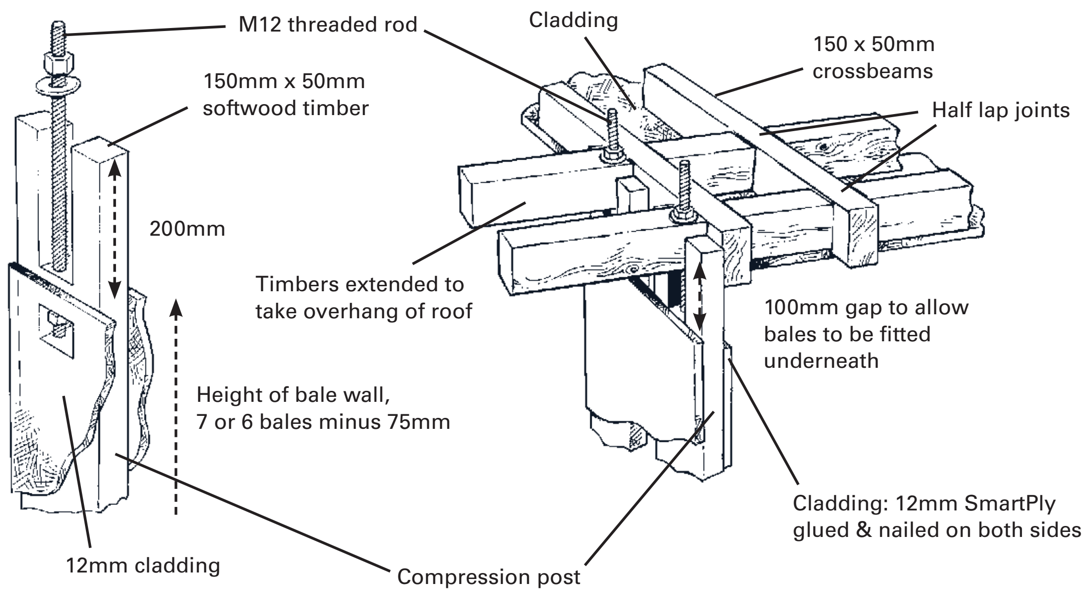
bale and the underside of the frame. If the frame is strong enough then bottle jacks can be used to compress the straw downwards from the beams of the frame, rather than using ratchet straps tied to the foundations. To do this a solid metal plate needs to be placed on top of the straw, and the jack extended between this and the top beam of the frame. Then, if you've designed the frame correctly, a whole bale will fit in the space you have created and you can carefully pull out the metal plates as you remove the jacks. Alternatively, you can design the frame so that you have a timber plate at compression level, which remains permanently in the wall. Again, the straw beneath can be compressed using bottle jacks or ratchet straps, and then the timber plate is fixed permanently to the posts either side, and you can carry on building above it.

Sworders Ltd, a fine-art auctioneers based in Stansted Mountfitchet, has had its new saleroom built using this method, with its Director Robert Ward Booth as the driving force and amazonails as consultants. This is pictured in the colour section of this book.

Lightweight frame technique

This method uses the structural properties of the bales to enhance those of a lightweight timber framework. The frame is so minimal that it could not stand up alone, and requires temporary bracing and props to give it stability until the straw is in place. The straw is an essential part of the structural integrity of the building, more so than the timber, and it works together with the timber to carry the load of floors and roof. Small timber posts,

SLOTTED POSTS AND WALLPLATE DESIGN FOR LIGHTWEIGHT FRAME METHOD



usually 100mm x 50mm (4″ x 2″), are located at intervals and either side of window and door openings and are designed such that the timber wallplate or roofplate, at first floor and/or roof level, can be slotted down on to the posts once the straw is in place and the bracing and props are removed (illustrated opposite), allowing the bales to be pre-compressed manually using various different methods. This could be by ratchet straps, or threaded rod can be used, depending on the design. Compression of the straw is essential to achieve enough stability of the walls for structural integrity and so that they can be plastered. In two-storey buildings the first floor needs to be lowered before the first-floor walls are installed so that the posts have free movement through the wallplate. The posts do not become fully structural until the walls have been compressed and then the timber is permanently fixed to the wall and roofplates.

Hybrid and other methods

There are many types of straw building that use a combination of ideas from the above techniques, or use new ideas. Being so simple, using straw allows for invention during practice. For instance, it's possible to build well-insulated loadbearing walls to protect your house on the cold north side and combine this with a framework method on the south, allowing for lots of windows to maximise solar gain. The two-storey house that won the Grand Designs Eco-Home of the Year Award 2008 was designed like this. All it takes is a bit of design ingenuity to make the rigid parts work with the flexible parts. Other methods have been used at different times around the world too. For instance, 30 years ago in Canada, Louis Gagné pioneered a bale building method using cement mortar between the bales, called the Mortared Bale Matrix. The bales were used much more like bricks, stacked in vertical columns so the cement mortar, in effect, formed posts between each stack and the whole building was cement-rendered inside and out. This approach is rarely used now because of the knowledge of simpler, more environmentally conscious and more enjoyable methods, but it is occasionally practised, particularly in France, through the French connection between Quebec and Europe.

In Germany they suffer from having prescriptive Building Regulations (unlike ours, which are guidelines), which means they are not officially allowed to build using the loadbearing method. This is limiting in terms of being able to experiment and to use new and simpler techniques. They have to use straw as part of a timber frame method, instead of the other way round, and follow official practice for timber frame, which means placing a horizontal timber between posts at every fourth course, on top of the straw. In practice they use this to compress the straw in another version of the compressive frame technique, which works very well.

There are many types of strawbale building that use a combination of ideas from different techniques, or use new ideas. Being so simple, using straw allows for invention during practice.

Other aspects of strawbale building

Straw is a very different material from others we have become used to working with in the twentieth century, such as cement or timber. As we have seen, it is natural, breathable, flexible, non-toxic, low in embodied energy, safe and fun to work with. Once it has finished its usable life as a building material it will go back to the Earth as part of the natural cycle of nature without creating any waste, damage or pollution. So in designing with straw it is sensible to use other natural materials as well, as like goes with like. Therefore you will find roofs and floors insulated with sheepswool, hemp or recycled paper, solid floors made of limecrete and insulated with recycled glass or blown clay, and roofs covered with cedar shingles or planted with sedum. Once you start thinking about a natural system of building instead of an unnatural one you begin to see how possible it all is.

When installing other aspects of the building, such as the services, plumbing and electrics, or the roof covering, these are done in much the same way as you would expect in a conventional house, but with thought given to the way the building needs to breathe and be flexible, minimising the environmental impact of manufactured materials.

Strawbale building has become much more than simply building a house with straw walls. It is now leading the way in providing an affordable solution to the need for thermally efficient housing, with very low embodied energy, using natural materials. Therefore it is common to design foundations without using cement or deep trenches. In the same manner, instead of cement renders and plasters, traditional lime and/or natural clay renders and plasters are used. Most strawbale houses, of whatever type of construction, are plastered inside and rendered outside, so that when finished they can look very similar to a traditional-style cottage, very beautiful and with deep walls – it is hard to tell that they are made of straw. The walls need to be protected from the weather using either several coats of limewash, reapplied, as with all painted houses, every few years, or an active silicate paint, which is a mineral-based paint that bonds with the quartz in the render, remains vapour-permeable, and needs reapplying only every fifteen years.

Durability

Because of the simplicity of strawbale building, it is possible to build a wide range of quality structures, from a strawbale shed that might only last ten years to a strawbale house to last several generations. We can design to a standard of 200 years minimum – anything less is not sustainable, either environmentally or financially. In the UK and Ireland, the oldest buildings are fifteen years old, and some of the early ones were never intended to be more than experiments. However, there are now two-storey semi-detached loadbearing homes for social housing, classrooms and whole schools, retail spaces, centres for community groups and new extensions to existing houses, as well as hundreds of owner-built houses, offices, studios and garages, animal shelters, food and machinery storage barns, and so on, all of which are expected to have a usable life of more than 100 years. In the USA, where it all began, there are about a dozen

houses built around 1900 that are still inhabited and in good condition, and thousands built since the revival began in the late 1970s. **No strawbale building in the UK or Ireland has ever been refused planning permission or building regulation approval on the question of durability.**

The key to durability with a strawbale house, as with any other, lies in good design and detailing, quality work, and maintenance when necessary throughout the building's life.

Design pointers

- Raise the first course of bales up from the ground by at least 300mm (12"), preferably 450mm (18"); put a 450mm (18") overhang on the roof to protect the walls from rain, and you won't go far wrong. 'A good hat and a good pair of boots' – just like cob buildings!

- When using the loadbearing technique, distribute the loads as evenly as possible around the whole building. Never use point loads.

- The roof weight must be placed on the centre of the walls, not on one edge or another.

- The key to durability with a strawbale house, as with any other, lies in good design and detailing, quality work, and maintenance when necessary throughout the building's life.

- Avoid using metal in the walls if at all possible – and if it's not possible to avoid using it, wrap it in hessian or something similar, since it is a cold material and may encourage warm, moisture-laden air from the inside of the house to condense on it.

- Loadbearing houses are subject to settlement as the straw compresses under the weight of the floors and roof. Allowance for this must be designed in by leaving settlement gaps above doors and windows, even when using impressive-compressive methods. See Chapter 10 for more details.

Chapter 4

BALES TO BUILD WITH

The nature of straw

If we leave a bale of straw out in the field to be rained on, it quickly becomes too heavy to lift because of water saturation and is of no use other than as mulch for trees. However, if we stack lots of bales carefully out in a field, raise them off the ground and put a good roof over the top, they will withstand the weather and the outside edges simply get wet and dry out again. Talk to any older farmer and she or he will tell you that this is how straw (and hay) was traditionally stored – in the field for ease of access. The bales would be raised off the ground first, usually by using a sacrificial layer of bales (i.e. those that would go to waste later) laid on edge, and the rest would be stacked flat, with a roof of thatch over the top. The sides of the bales would be exposed to the rain and wind, but getting wet was not a problem. Straw does not 'wick' (suck) water into itself like concrete does. It simply gets wet as far as the force of the wind can drive the rain into it. When the rain stops, the natural movement of air or wind around the bales dries them out. This cycle of wetting and drying does not normally damage the bale.

There have been problems in recent years in some modern grain crops. If the straw contains an excess of nitrates (owing to the use of too much fertiliser) and then it gets wet, the combination of the two can create great compost! This fact is utilised when using straw for DIY urinals, as the added natural nitrate helps it decompose. Too much nitrate in straw from farming practices has been a particular problem with thatch, which obviously gets wet rather frequently in our climate, but shouldn't be a worry with straw walls as they will be designed so that they don't get wet. The time to be aware of this issue is during transportation and storage.

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Modern growing methods and the development of hybrids for grain crops has definitely changed some of the properties of straw, making grain for food more commercially viable but not necessarily improving the durability or length of straw for building. Organic farmers often grow older varieties

of straw and do not treat their crops with commercial fertilisers or pesticides, which gives it some advantages over non-organic straw in that it is longer and will not rot down quickly. Clay plasterers report that organic straw has a natural waxy surface that prevents uptake of water, which is not what they want for plastering but is what we'd like for wall building as it is more durable. Allergy sufferers also find organic straw easier to live with as it doesn't contain chemical residues. Sometimes organic straw can contain a lot of weeds, which makes it more like hay than straw, so it needs to be selected carefully. In fact, however, it is usually quite hard to find organic straw bales, because it is mostly used by the farmers who grow it and is not sold on.

How to choose good building bales

Bales should be dry, well compacted with tight strings, be of a uniform size and contain virtually no seedheads. They must not be damp, and must be protected from damp during the building process. Safe moisture levels for the prevention of fungal and bacterial growth are as follows.

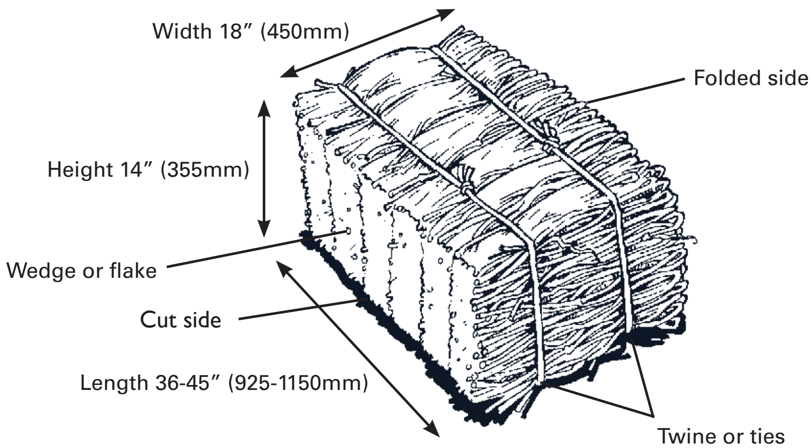
Moisture content

Moisture content should not exceed 25 per cent dry-weight basis. This means that the weight of water in the bale should not be more than 25 per cent of the weight of the same bale if it was thoroughly dried. Or, **moisture content should not exceed 20 per cent wet-weight basis**, meaning that the weight of water in the bale should not be more than 20 per cent of the weight of the same bale when wet.

Relative humidity

Relative humidity should not exceed 84 per cent. This means that whatever the maximum amount of water vapour the air can hold before that vapour condenses out as water, the bales must not contain more

A TYPICAL BALE



than 84 per cent of it. The relative humidity of air changes with temperature: air holds more vapour if it is warmer. See Appendix 1 for more information on moisture content and relative humidity.

Bale standard

- Bales should be as dense and compact as possible. The baling machine should be set to maximum compression; in general this means bales contain about one third more straw than usual. Weight should be between 16kg and 25kg.

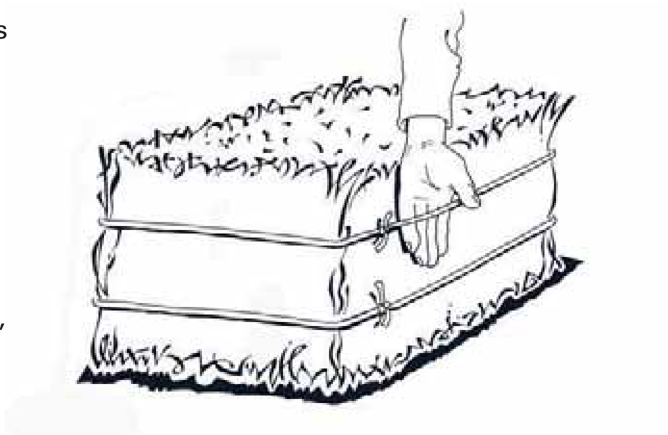
- Bales should be more than twice as long as they are wide and are usually measured in imperial units rather than metric: about 41” (1.05m) long on average is good. Most baling machines produce two-string bales that are 18” (450mm) wide x 14” (355mm) high and are of variable lengths from 36” to 45” (900-1125mm), although a few machines are 20” (500mm) wide and 15” (390mm) high. Mini Heston bales of 7’10” x 3’10” x 2’3” (2.4m x 1.2m x 0.7m) or Quad bales of 7’ 10” x 2’7” x 2’7” (2.4m x 0.8m x 0.8m) can also be used, and are especially good for building extremely large spaces such as warehouses.

- Strings must be very tight, so that it is difficult to get your fingers underneath. They should be about 100mm (4”) in from the edges of the bale and not sliding off the corners. String should be sisal or hemp baling twine for a low environmental impact, or polypropylene, but not wire, as metal is best avoided within a straw wall.

- The type of straw is immaterial as long as the above guidelines are followed. It can be wheat, barley, rye, oats, etc. Straws should be long, 150mm (6”) minimum, preferably 300-450mm (12-18”). Rye would be a good choice as it contains a natural fungicide so is very resistant to rot, but it’s almost impossible to get it in the right size of bales. Winter wheat would be the second choice as it is more durable, having had to survive harsher weather conditions.

Do not confuse straw with hay or grasses. Straw is the baled-up dead plant stems of a grain crop. It has had virtually all its seed heads removed, and contains no leaves or flowers. It is a fairly inert material, with a similar chemical make-up to wood. It does not decompose easily, usually requiring the addition of nitrates to do so. Hay, on the other hand, is grass baled up green, with lots of feedstuff (leaves, flowers, etc.) deliberately left in there because it is fed to animals. It readily decomposes, unlike the dead plant stalks of straw.

The age of the straw does not matter as long as the above conditions are fulfilled, and it has been stored correctly. All the



above conditions apply equally to all bales, whether they are being used for loadbearing or infill.

Bale size

It is important to know the size of bales you will be using before finalising the dimensions of foundations, wallplate, roofplate, etc. Bales can vary a lot in length, from supplier to supplier and within each load, since whether or not the straw is picked up uniformly as it is baled depends on the skill of the tractor driver and the evenness of the field.

In practice, relying on the farmer to tell you the length of bales is not a good option, as you are unlikely to get an accurate picture. Besides which, you will need to satisfy yourself that the straw is baled dry, and kept dry while in transit and storage. It is far better to look at the bales once they're harvested and determine the average length of bale at the same time. The best way of doing this is to lay ten trimmed bales (see page 75) tightly end to end. Measure the whole and divide by ten to find the average. (It is almost impossible to measure the length of one bale accurately). However, if you find that your delivered bales are not the same length as you expected, this is not an insurmountable problem. It may mean a little more work in shaping the bales to fit, but this is straightforward and not too time-consuming.

Construction-grade bales

As more and more buildings are being constructed out of straw, this has given us the opportunity to really find out which are the best bales for building. 'Construction grade' bales can be ordered from particular wholesalers who are familiar with the above requirements. These are becoming more readily available, and suppliers can be found listed under Agricultural Merchants in directories. These bales are often made using a modern baling machine which creates very dense, uniform bales that are delivered to site in packaged bundles with 21 on a pallet. Their dimensions are 42″ x 14″ x 18″ (1,050mm x 355mm x 450mm).

Knowing what your bale dimensions and properties are makes a big difference when you are designing and building. If using pre-compression methods, these bales are so dense that they will each compress by no more than 10mm (⅜″), so you can also predict with greater accuracy what the settlement of the walls will be and factor that into the building process. Although it is still possible to use other types of bales, you must remember that there may be greater settlement on the walls, and allow for up to 25mm (1″) per bale if using pre-compression methods or a reasonably heavy roof.

It is possible to harvest and store straw in bales of uniform length and moisture content, ready for the building market each season, and we would expect wholesalers to start doing this as demand increases. As long as the bales are kept dry and well ventilated, they can be stored for a long time before using. As demand increases, so will the reliability and availability of supply.

The cost of bales

The cheapest way to buy bales is straight off the field after they've been made, and to buy locally so as not to pay large transport costs. This has the added benefit of minimising the environmental impact of transportation. If you collect them yourself, they can cost as little as 80p per bale plus your fuel costs.

When you consider that the average $100m^2$ three-bedroomed house will use about 350 bales, this represents a material cost of only £280! However, most of us will have to buy bales and have them stored for us and then delivered to site, which will increase the price.

Construction-grade bales bought in bulk from a wholesaler, delivered to the site, can cost about £2.50 each, which would bring the price of 350 bales up to £875 (plus VAT). These bales generally have about a third more straw in them than ordinary bales.

Although the walls represent only about 16 per cent of the total costs of a finished building, using straw instead of masonry is a significant saving and becomes more so for construction firms building more than one house. Together with this, the labour time involved in strawbale building is vastly reduced once the labour force is familiar with the material. Plus, you can run training courses to install your straw, learn how to do it, build your walls, have no labour costs and have a lot of fun!

Can you afford *not* to build with straw?

Know your bales – a training workshop in Todmorden. *Photograph © Roger Livesey*

Chapter 5

BALE PLANS

Getting started

Think about what you want your strawbale house to look like and how you want it to feel inside. Try to forget anything you've been told about building and imagine your ideal space, however wild that might seem! Then work within the practical limitations of the bales to come as close as possible to your dream.

The design of a strawbale house is usually simple and elegant. Straw buildings are based on a block design and therefore different elements of the structure can be built up easily from the shape and dimensions of the foundations. Each section of the house has an obvious relationship to the other sections, and many different houses can be designed quickly and easily from the same basic plan.

The design of a strawbale house is usually simple and elegant. It follows common-sense principles.

For most small buildings, it should be possible for owner-builders to design their own houses with a little guidance, and certainly to work out the straw elements.

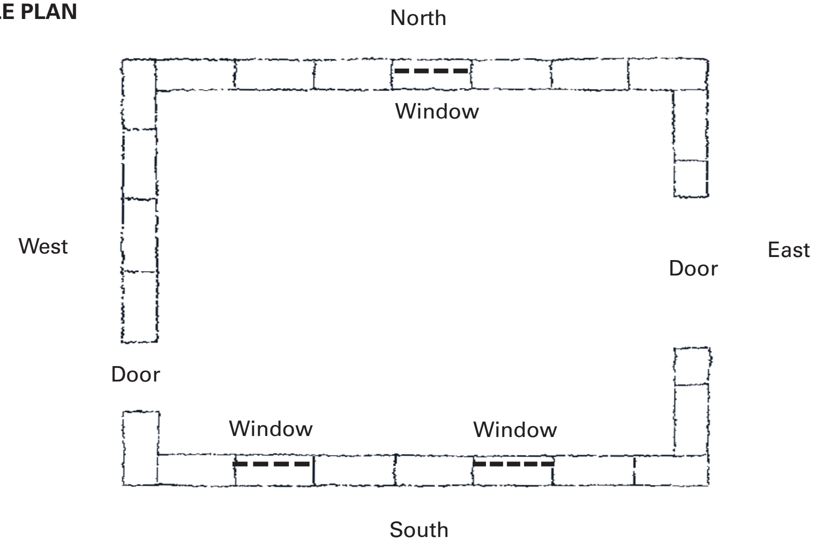
The way a strawbale house goes together is simple. It follows common-sense principles and it is effective. By using this book, you should have no difficulty in working out the construction drawings and methods for any type of domestic dwelling.

Once you've decided on what the building is for, what you want it to look like, and what you want it to feel like, think about the building's orientation, design the rooms you live in most to face south, and have more or larger windows on this side to maximise solar gain.

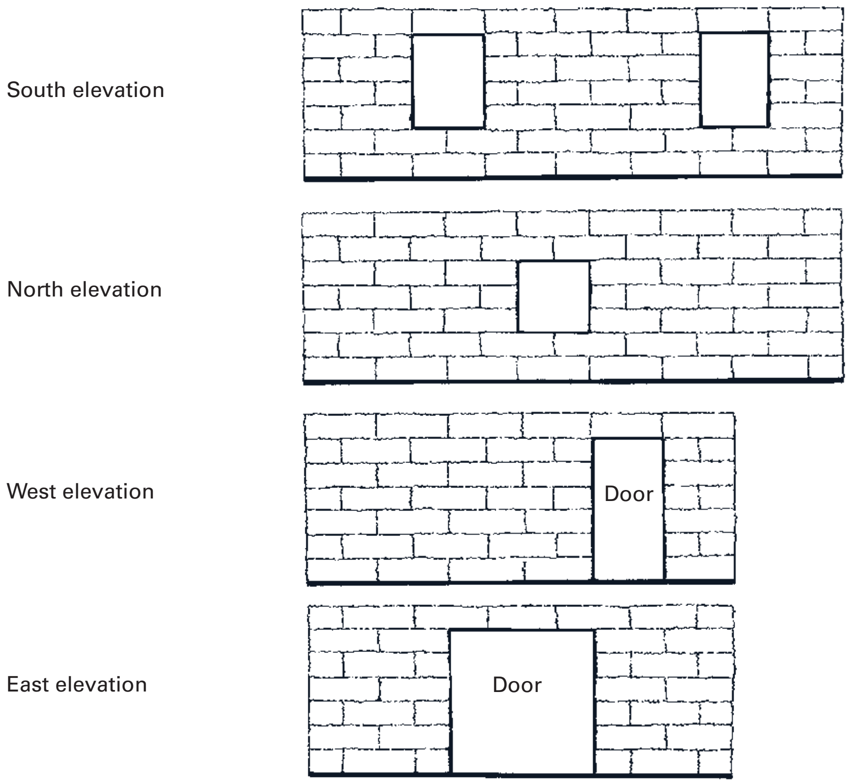
Draw the shape of the building you require, as though you were looking at it from above. This is called the PLAN view. You will need to know what size your actual bales are (see Chapter 4). Draw in the shape of the bales, their width and length, planning where they lie on the first course of the wall, as in the drawing overleaf.

Now imagine you are looking at the finished building, standing on the ground looking north, south, east and west. Draw the face of the building you see from each direction, showing again where each bale is and how they turn corners or curve, etc. These drawings are called ELEVATIONS.

BALE PLAN



BALE ELEVATIONS



From accurate bale plans you can work out how many bales you need, as well as how many hazel stubs (two per bale on the first course), pins (two per bale for the fourth and sixth courses), staples (in every bale where it changes direction, e.g. corners) and other quantities of materials. Details of foundations, windows, first floor and roof can be worked out. You also now have the basis for drawing your own plans for planning permission.

Principles of bale design and layout

- Before you draw your final plan, and before you finalise the dimensions and lay out the foundations, you need to know the dimensions of the bales you will be using, as they can vary a lot!
- The bale plan should be made up of a whole number of bales wherever possible. Any half bales should be only at an opening.
- Do not have any places in the wall (e.g. beside a window) that are less than half a bale in length.
- Window and door openings must be at least one bale length away from corners in loadbearing designs.
- If at all possible, choose window and door sizes that, together with their framing, are multiples of bale dimensions.
- Try to design frameworks so that the distance between posts is equal to a whole number of bales or half bales, thereby reducing the labour time involved in customising.

In a loadbearing design the walls will settle a bit once the weight of the roof is on, or after you have done the pre-compression, so allow for this by leaving gaps above windows and doors that can be filled in later. With construction-grade bales, settlement in a seven-bale-high wall should be about 70mm (2¾″); for less-dense bales you need to allow for more settlement than this, unless you have a lightweight roof. The amount of settlement depends on the density of the bales and the amount of loading applied to them (such as the weight of the roof, whether there is more than one floor, etc.).

Interestingly, some of the laboratory tests done to find out how much load strawbale walls can carry have appeared to show that only single-storey houses can be built this way. This is patently not true in practice! We need to be very careful when looking at research findings and especially when talking to engineers, as they are often not very familiar with strawbale building in practice and may test or calculate for situations that turn out to have no relevance to actual performance. Common sense and practical experience should be our guides. After all, it was engineers who proved that a bumble bee cannot possibly fly . . .

Chapter 6

SAFETY AND TOOLS

In general, there will be fewer accidents and mistakes on site if everybody is happy and well motivated. It is good practice to encourage the whole team to be aware of each other, of each other's roles, and of how each separate action is part of the whole achievement. It can be very useful for everyone to meet together at the start of each day, to share thoughts or reflections on the work to be done or the manner of its doing, and discuss possible problems or areas that will need cooperation or greater care. If we can recognise our interdependence with each other rather than be in competition, this will help to engender a caring and considerate workforce, where each individual is responsible for her or his own self but also has regard for others' welfare. This is especially necessary on a self-build site where people have different levels of skill or knowledge.

Strawbale building sites have become renowned for their ethos of working together, sharing knowledge and skills, equality for women, enjoyable learning and fun. But there is no reason why these qualities cannot be encouraged on *all* building sites.

Knife

Tape measure

Baling twine

Safety on site

The following basic guidelines will help to ensure that nobody has an accident.

- Every building site, even if it's your own home, should have a first-aid kit available and **everyone should know where it is!**
- There should be no smoking anywhere on site or around stored straw.
- Always keep the site tidy. Scaffolding and working areas should be cleared and tidied each evening before finishing. It is helpful to store materials and rubbish, etc. in specific places to keep a sense of order.
- Have a central place for tools so that any that are not being used can be put back, and can be found when needed.
- Never leave tools lying around. Each person should be responsible for the tools that she or he is using, should know where they are, and should put them away when not in use.
- Sharp tools should be sheathed or put away when not in use.
- All electrical tools should be unplugged when not in use.
- Do not leave electrical leads trailing across the site.
- All ladders must be securely tied.
- Never move a ladder temporarily and then leave it unattended.
- Stepladders and scaffolding towers, etc. should always have a firm footing.
- Hard hats should always be worn when anyone is working overhead.
- Extra care should be taken when using heat or open flames, e.g. when connecting plumbing pipes together.

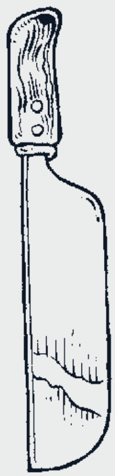
Tools for strawbale building

Strawbale building requires almost no specialist tools. A basic toolkit of items can often be found around the home, but if you don't already have them, they are relatively cheap to buy and not too difficult to find. As you become familiar with using tools, you'll find that particular ones suit you better than others, and you'll develop favourites. This may be because the handle is just the right size, or it does its job well, or it's well balanced, or because you like the look of it and it's familiar. **Developing a feel for tools can be one of the unexpected joys of working with straw**.

As with most things, there are different standards of quality available on the market. On the whole, it is best to buy better-quality tools even if they cost a bit more, because **poor-quality tools may be inaccurate, wear out quickly, or stretch!** They will certainly frustrate you and make you feel inadequate.

The following are some of the reasons for investing in good tools.

- You will be using them over a long time period, so they need to last.



Hay knife

Baling needles

Billhook

Persuader

- They must withstand normal wear and tear on a building site, so need to be robust.
- Some will probably get lost in the straw at times, and should be able to withstand this, at least overnight.
- Using tools that don't do their job well can make you think it's you, not they, that's the problem.
- Good tools, if well maintained, can last a lifetime, not just while you build your first house.

On the following two pages is a list of some of the most common tools you will need.

Main tools	Preferred type	Comments
Tape measure	5m long, with metric and imperial units together.	The hook on poor-quality tape measures may come loose easily, bend or break, or not be set correctly. Such tape measures may also stop returning into their holder, rust easily, or snap!
Stanley knife	With retractable blade for safety.	Any small hand knife will do, preferably on a string to avoid losing it!
Claw hammer	14oz (400g) weight or less, unless you are used to them.	Cheap hammers bend when pulling nails out, or become pockmarked on hitting nails. Their handles may pull off too!
Lump hammer	2lb (0.9kg) is sufficient unless you're trying to impress someone.	The head can fly off cheap ones!
Handsaw	Cross-cut panel saw.	A sharp saw is a dream to use, but a blunt one may put you off carpentry for life.
Axe	A side axe is best, but a splitting axe is useful too.	Get one that fits your hand size and strength.
Billhook	Any type will do.	This is an alternative to the axe, and extremely handy if you're used to using one.
Persuader	Long handle, large, lightweight head.	Otherwise known as a fencing hammer. No strawbaler should be without one!
Baling needles	Lightweight steel, pointed, with two holes at one end.	Should be long enough to go through the width of a bale, and sturdy enough not to bend too much.
Gloves	Fabric with criss-cross plastic.	Most work gloves are made for men with big hands, so choose carefully.
Hedge clippers	Any type will do.	Need to be really sharp, as straw is particularly tough to clip.

Other useful tools	Preferred type	Comments
Combination square	For marking 90° and 45° angles.	Cheap ones may bend or not measure angles accurately.
Bevel	For marking angles from 0° to 180°.	Most common problems are the tightening screw handle getting in the way when marking, or not staying tight.
Hay knife	Large single blade.	A traditional tool that is extremely effective, but may be difficult to find. Can be made by a blacksmith from an original.
Electric drill	Powerful, with hammer action.	See 'Power tools and electricity on site', opposite.
Earth trip	Plugs directly into a socket.	An essential protection when using 240V power tools on site.
Screwdrivers	A selection of sizes, both straight head and posidrive or Phillips.	Can also use battery powered. Note that the heads on cheaper screwdrivers or bits are made of softer metals that will wear out rather than turn a difficult screw.
Spanners and wrenches	A selection of sizes.	May need both metric and imperial sizes.
Crowbar	Long but not too heavy.	Can be used for many different jobs.
Sledgehammer	Short- and/or long-handled.	Possible alternative to the persuader (see 'Main tools'), but can encourage too much macho behaviour.
Garden strimmer	Best with a metal cutting blade.	All types will work, but be careful not to get one that's too heavy, as it has to be used sideways.
Crocodile or alligator saw	Electric or powerful battery.	Must be very sharp, but can get very close to the straw for a nice neat finish and can create lovely details around window and door openings.
Chainsaw	Petrol driven or electric.	A very dangerous but effective tool; needs to be kept sharp. May need constant cleaning as straw will clog it up.
100mm (4") angle grinder	Electric.	Use a wood carving (arbutus) blade. Again, a very dangerous tool: be careful!
Hedge cutters	Petrol or electric.	Must be very sharp. Don't hire them at the end of the season because they'll be blunt and frustrating!

Clothing and safety equipment

- When working with straw it is advisable to wear a long-sleeved shirt and long trousers because straw stalks can be quite prickly.
- Gloves are also a must, at least for some aspects of the work.
- Overalls can be handy when doing particularly messy jobs such as plastering or painting.
- Goggles, ear protectors and dust masks may be needed for certain jobs.
- Hard hats must be worn if anyone is working overhead.
- Stout boots are needed to protect your feet on uneven surfaces and from falling objects.
- As loose straw is a fire hazard, have a long enough hosepipe ready in case.
- Make sure there is a first-aid kit on site.

Power tools and electricity on site

Electricity, at the voltage that is supplied to us domestically, is powerful enough to kill outright if we make direct contact with it. This is why there are so many safeguards in the home, to ensure that this never happens. On construction sites, the risk of cutting through a cable is so much greater than at home that on major sites power tools are used at a lower voltage than the normal 240 volts, so that any potential shock is not life-threatening. Tools such as drills are connected via a yellow round pin socket to a transformer, which is connected to the mains electricity by a short lead. The transformer converts the usual supply of 240 volts to 110 volts. When using power tools at home, or on a self-build site, it is not common to use 110V equipment, and in fact 240V equipment is sold as standard in all DIY shops. When used according to manufacturers' instructions this is not dangerous. However, with the increased risks on a building site, it is a sensible precaution to use an earth trip plug for each electric tool. This looks like an ordinary adaptor that plugs into the socket; the electrical tool plugs into this. What it does is to cut off the power supply if there is a short in the circuit, such as would occur if the cable were cut or wires were immersed in water. Electrical tools from a hire shop will be supplied to work at 110V with a transformer.

Battery-powered tools with rechargeable batteries are increasingly popular and useful. The main ones in use are drills and screwdrivers, but you can also buy circular saws, jigsaws, etc. They have a huge advantage over standard plug-in tools in that they don't have any trailing leads to trip over or cut through.

The main issues to consider are as follows.

- The tool must be powerful enough for the job it is required to do, otherwise it can be very frustrating. 18 volt or higher is a good power rating.

- Batteries should store enough charge to give a reasonable length of time for usage.
- Two batteries are best, then one can charge while the other is being used.

Handy tips

- Buy brightly coloured tools, and/or mark them with coloured tape: they will be easier to find when you have lost them somewhere in the straw!
- When customising bales (see page 76), cut the original strings at the knot, and hang them up in a convenient place so they can be reused for the next customisation.
- Never stick baling needles into the ground, as the holes get clogged with soil. For safety, and so you can find them again, stick them upright in a spare bale.

The strawbale persuader. *Photograph © Press Association*

Chapter 7

CEMENT-FREE FOUNDATIONS

An introduction

Foundation designs for strawbale buildings have been developed by going back to basics and thinking through how and why traditional designs worked. What's great about this approach is that it keeps things as simple and cost-effective as possible AND provides foundation solutions that are applicable to all buildings, not just straw-bale ones.

All buildings need to have some sort of a foundation on which to build. This may simply be the natural foundation of the earth beneath, which could be bedrock, gravelly soil, firm clay, etc., but in today's world we are more familiar with artificial foundations such as poured concrete strips and slabs. As the foundation has to carry the weight of the walls above it, and other loadings such as floors, furniture, roofs and even snow in winter, it is important to know what type of earth (or subsoil) is found on your building site. Different types of earth will be able to carry different weights. Gravelly soil, for instance, will carry much greater weight than soft clay. On the other hand, if you increase the surface area that bears the weight on soft clay – much like wearing snowshoes in the snow – even this can take the weight of a house. For a small building constructed of lightweight materials, there is obviously no need to build massive artificial foundations on any type of soil. Equally, for a heavy building built on what we call 'good bearing soil', there is also no need to use deep foundations. Almost all the buildings in the UK and Ireland that are more than 200 years old have natural foundations with little or no artificial ones. They often use larger stones at the base of the wall, making it slightly wider than the wall itself. In all cases, the builders removed the topsoil and dug down to something solid, and because they chose their building sites well, this was usually just below the topsoil.

Almost all the buildings in the UK and Ireland that are more than 200 years old have natural foundations. The builders chose their building sites well, removed the topsoil and dug down to something solid.

There are hundreds of thousands of houses still lived in today that can be excavated by only 150mm (6") or so to find they are sitting on the ground itself, and yet they are completely sound and safe. **Unfortunately,**

there are many misconceptions about foundations that are partly caused by the rise in popularity of cement and concrete. In some building colleges, students are taught that buildings can only have foundations made of concrete, despite the evidence to the contrary that surrounds us. Throughout learning about strawbale building, you will be encouraged to look at what's around you, to keep things as simple and straightforward as they can be. There is no need to overcomplicate anything, only to **understand what it is that we want to achieve and make choices based on the different ways that it is possible to do so**.

We use foundations to achieve a stable base that distributes the weight of whatever is built upon it over the ground beneath, to be sure that there is no unequal settlement throughout the building, to allow flexibility for the building to move over long periods of time as the ground itself moves, and to keep the inside of the building dry. In the past, natural materials were used to protect buildings; nowadays, manufactured ones are used, and they do not perform in the same way. So we also need to know the essential properties of materials in order to use them wisely.

It is necessary to discuss the causes of damp in buildings because there are so many misconceptions, about rising damp in particular. If we can understand the causes then we are more equipped to design well and prevent it happening. This applies to all buildings, not just straw ones, and the principles discussed below can be applied universally.

Causes of damp in buildings and their solutions

Damp problems in any building, straw or otherwise, are caused by poor design, lack of maintenance, and inappropriate use of materials. They are slow to show themselves, sometimes taking 20 or 30 years, which is why it can be hard to understand why some of our buildings have become very damp, because cause and effect are not so obvious. But very few buildings in the UK and Ireland actually suffer from rising damp, contrary to popular belief. Damp is almost always caused by something else instead.

Whatever a wall is made from, it can be divided into three main areas that need attention: the base, because of contact with the wet earth or from splashback as rain bounces off the ground on to the walls; the top, owing to rain running off the roof; and the face of the walls themselves, in driving rain.

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Poor design includes factors such as poor detailing between two different roof pitches, so that rain running off one is not prevented from running into the wall of another; or inadequate rain protection in severe weather.

Common causes of damp due to lack of maintenance include:

- damage to roofs

- lack of maintenance of gutters and downpipes
- vegetation growing up around the foundation, holding permanent damp against the wall and preventing moisture from leaving.

Inappropriate materials use may include:

- use of cement pointing and rendering on older lime-mortared houses
- use of cement mortar and plasters for renovations in older houses that were originally lime-plastered.

At the base of the wall, foundations need to be designed so that:

- moisture from the earth cannot travel upwards through them
- rain bouncing from the ground is not able to pass through to the interior of the house
- any moisture that does find itself in the foundations can escape harmlessly to the earth or the exterior.

In the past, moisture was prevented from rising up from the earth by using non-porous building materials such as stone, e.g. slate, granite and some sandstones; or bricks, e.g. engineering bricks. These would be laid with vapour-permeable lime or clay mortar (which also does not allow capillary action to take place) and coupled with good design above ground, e.g. double-skin walls with rubble infill. A natural slate damp-proof course would be used if the building material was porous or was expected to become so over time, e.g. some sandstones and brick.

Such materials and design were also used to prevent most driving rain from entering the face of the walls. Moisture that did enter through small cracks or damage would be caught by the central rubble, filter down inside the wall and exit safely through the vapour-permeable joints once it had stopped raining.

Problems can occur with these designs for all the reasons described above, and also if:

- modern materials have been used for renovation or repair that are not vapour-permeable or flexible: most commonly cement pointing, cement rendering and plaster
- alterations have been made to the walls using poor workmanship and inappropriate choice of materials, e.g. a new window has been added using cement mortar, which has been allowed to fall down into the rubble infill. This creates a bridge for damp to travel across into the internal skin of the walls – rain can enter the building via the mortar joints but instead of filtering down through the rubble and out through lower joints, it hits the dropped cement and runs along this into the interior of the house.

Traditional building design accepted that rain and moisture could not be kept out of walls, but made sure that any that got in could escape safely to the outside, and also used flexible materials to prevent cracking. In the twentieth century we decided to build rigid waterproof buildings that moisture could not penetrate, but in practice this has never worked well because as soon as these

materials crack, moisture gets in, filters downwards, and can't get out again. This is one of the main causes of damp in modern houses.

Cement is used in buildings as a rigid, waterproof and strong material. Unfortunately, all these properties can contribute to damp problems. Firstly, its rigidity means that as the ground (and therefore the building) moves imperceptibly over time, the cement cracks because it is not flexible. Then, rain gets into a building through these cracks, filters down behind the stone or render finish, and builds up at the base of the wall because it cannot get out again as the cement mortar joints are waterproof. Also, the strength of cement means that it is often stronger than the brick or stone it is holding together and so erosion of the weaker material happens at the interface between the two, causing the brick or stone to flake away and the cement pointing to remain intact. This creates cracks through which damp can enter, causing problems over long periods of time.

The problems caused by inappropriate use of materials and design take years to become apparent, so it can be hard to accept that the damp at the bottom of your 150-year-old stone-and-lime kitchen wall is caused by the cement pointing the previous owner did 30 years ago coupled with the new gypsum skim you plastered the walls with two years ago.

Using porous materials with a damp-proof course (dpc) on top shouldn't be a problem as long as there are no holes in the dpc – which is easier to ensure with slate than plastic. But if the dpc extends the whole width of the wall, e.g. on top of poured concrete foundations, then we have created a waterproof barrier that allows moisture to collect at the base of the wall just where we don't want it and prevents it from filtering downwards and safely out of the building. Modern buildings use a tray dpc that directs any moisture at the base towards the outside wall not the inside, as part of a cavity wall system.

The metal wall ties that are used to hold the two wall skins together in cavity-wall construction also hold any cement mortar that is dropped into the cavity, a common occurrence when bricklayers are working fast and not caring too much about quality. This mortar then becomes a bridge for moisture to pass along to the inside of a building, and causes problems years later.

Designing foundations

When thinking about designing foundations, the first thing to decide is whether the ground itself can provide us with a natural foundation. If it can, then there's absolutely no need to dig it away and create an artificial one. It has become the norm not to think about what the actual ground conditions are on a given building site, but to go for the lowest common denominator, a solution that will work in pretty much every situation, regardless of what the earth is doing for us, and dig 450mm- (18")-deep trenches and fill them full of wet concrete. In many cases, this is not necessary and thus creates an unjustified environmental impact that can also be expensive! But it does mean you don't have to think or have interesting discussions with your engineer or building inspector.

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For stability, find out what your subsoil is

There are several ways you can find out what your subsoil is and if it's good bearing soil.

- Look at houses in the area (as long as they're pre-1900 and made without cement) and see what their foundations are made of. If they're quite shallow, you've almost certainly got good bearing soil. Not only that, but you can use the same foundation designs for your own house.

- Ask older people in the area, who might remember houses being built in their youth, what foundations were like then.

- Consult your building inspector, who should have a good local knowledge of older houses and subsoil in the area.

- Dig two or three pits about 800mm (31") deep in the place where your foundations will be, have a look at the profile of the soil, and take photographs of it to show your building inspector. Does it seem solid? Does any of it fall away? What's it made of – is it gravelly soil, stony or clayey?

An average two-storey strawbale house has a bearing weight of about 60kN/m^2. This means that every square metre of foundation has to be able to hold up 60kN of weight – much less than a conventional brick-and-mortar building (see table overleaf). The foundations of a typical strawbale house are 450mm (18") wide, which has the advantage of spreading the weight of the building over a wider-than-usual surface area.

The majority of building sites in the UK and Ireland are on good bearing soil, and this type of soil will easily take the weight of a strawbale house (and most other houses in fact, including stone ones). The types of soil where we need to think a bit more carefully about foundations are:

- silty soils

- heavy clay soils

- made-up ground (i.e. you're not sure what it's made of because it isn't undisturbed subsoil)

- wet soils

- moving sand soils.

All other types of subsoil should be good bearing soil.

For flexibility, use appropriate materials

There was a major change in foundation design that occurred around the 1920s and 1930s when cement started being used in mainstream construction, and this was a shift from flexible foundations to rigid ones. It might seem strange to think that foundations and whole houses made of stone or brick could be flexible, but because of what

COMPARATIVE WEIGHTS AND FOUNDATION LOADS FOR A TWO-STOREY HOUSE				
	Strawbale	Timber frame rendered	Timber frame brick clad	Traditional cavity brick and block
TOTAL WEIGHT (kg) Excludes foundations	41,300	31,100	53,400	76,800
TOTAL IMPOSED LOADS (kg) Roof, ceiling and floors	21,000	20,500	20,500	20,500
TOTAL (kg)	62,300	51,600	73,900	97,300
AVERAGE FOUNDATION LOAD (kg/m) Excludes foundations	1,950	1,680	2,370	3,120
ASSUMPTIONS Two-storey house with 50m^2 internal floor area at each level (based on 5m x 10m internal footprint). Tiled dual pitch roof with gable ends and flat ceilings. Suspended timber floors at first floor and ground floor. Average 17.5% openings in external walls. Imposed loads are the maximum allowable live loads in accordance with BS6399. Ceiling heights 2.8m at ground floor and 2.4m at first floor.				

Source: Peter Beresford of Structural Solutions*

the mortar is made of they definitely are! Lime and clay mortars have a very high degree of flexibility, whereas cement ones do not. We know that our old houses were and still are flexible, because they have changed shape over time. You can see in old houses around you that floors are no longer quite level and doors are no longer quite square, but in fact people seem to like this and will pay more for houses that have these quaint features. Despite having moved as the ground has moved over long periods of time, these houses have not become unstable. However, many houses built since the 1920s have experienced structural cracking, and have had to be repaired or demolished, as a direct result of using the rigid material cement as a mortar. Instead of working with the natural movement of the ground, we started trying to design houses that would

* Personal communication, August 2009.

somehow float on top of it, and this hasn't been very successful. Long expanses of wall laid with cement mortars need to have joints filled with a flexible material built into them to control cracking, which is why you see those ugly vertical joins every few metres in modern buildings. Victorian walls were able to run for miles around gardens and estates if necessary without any such join because the lime mortar they were built with did this job itself. Modern houses are far less durable and won't last several hundred years as their predecessors did, partly because of this lack of flexibility. This is not to mention the other undesirable effects to do with damp and condensation that are attributable to the use of cement in modern housing stock.

We know that our old houses were and still are flexible, because they have changed shape over time.

So it's really important to build flexibility into the design of your foundations, and you can do this by using flexible mortar made of either lime or clay.

For moisture control, use capillary breaks and vapour-permeable materials

All walls, whatever they're made of, whether brick-and-block or straw, will contain moisture because of normal human habitation – breathing, taking showers, etc. – plus foundations are in contact with the earth, which is often wet. So to keep the inside of our houses healthy and free from damp, we need to design a foundation and wall system that takes into account the ways moisture can get into the wall and provides pathways for it to escape naturally back out again.

If we make foundations of non-porous materials such as stone (though be careful, as not all stone is non-porous), engineering brick or recycled foamglass, then any moisture in the earth cannot travel upwards through them. There cannot be any rising damp, which is caused by capillary action wicking water through tiny spaces in materials. And if we use vapour-permeable mortars such as lime or clay then any moisture that does find itself in there will migrate out through the mortar joints.

Traditionally, a capillary break was used to prevent the movement of moisture from the earth into the foundation. This is a layer of stones all the same size and at least 75mm (3") thick, such that water cannot pass up through them by capillary action, because the spaces between the stones are too large for this to happen. In many European countries this is still the preferred method of providing a damp-proof course, and it is becoming more popular again in the UK and Ireland as we are thinking through some of the causes of damp and trying to find sustainable solutions for them. Capillary breaks can be used instead of a plastic damp-proof course, particularly underneath solid floors.

Moisture in the walls will migrate downwards very, very slowly, because of gravity, so we don't want a sheet of plastic catching this moisture and creating a problem in 20 or 30 years' time. Instead, we want walls to sit on foundations that allow any moisture to travel down through them and evaporate harmlessly out through the mortar joints. **One of the main problems with plastic damp-proof barriers is that they are waterproof!** The design

we want is not a damp-proof course but one with a capillary break, which will let water pass down through it but won't let it travel upwards.

For thermal efficiency, use insulating materials

To meet the challenges of the twenty-first century – to build houses that are energy-efficient and require very little fuel to heat them – we have to make sure that the foundations do not allow cold into the house via what's known as a 'cold bridge'. The space we live in needs to be wrapped in a complete thermal envelope, with no gaps. So, while taking into account all of the above points, we also need to choose materials that will act as a heat/cold barrier, and use enough of them to actually work! Ideally these materials need to be non-porous, loadbearing and environmentally sustainable as well. The only real option at the moment for the internal skin of a plinth foundation is recycled foamglas block. The infill between the outer and inner skin could be either a different type of recycled foam-glass (recycled foamglass [rfg], available in small chunks), or leca.*

Insulating materials need to be sufficiently insulating to at least meet Building Regulations, but the Regulations in the UK and Ireland do not as yet go far enough to provide thermally efficient houses. Although we know that we need to reduce our dependence on fossil fuels and our energy needs, which can be partially achieved by building houses that require very little heat, the government is reluctant to insist that the construction industry actually provides us with houses that do this. The cavity-wall system will never provide a thermally efficient, cost-effective solution to house building, and no amount of tinkering with it will alter this. However, if we did continue to use the cavity-wall system, the cavity would have to become very wide just to allow enough space to fit in the amount of insulation it would need to match the thermal efficiency of a strawbale wall.

Low-impact foundations

Clearly the most low-impact foundation you can possibly design is one that requires no intervention at all but simply uses the Earth itself. For all foundations the topsoil must be removed because this will always compress and compact, and if you have very deep topsoil this might mean that your foundation needs to be quite tall, to bring your building clear above ground level. But wherever you have good bearing soil, there is never any need to dig trenches into the subsoil. The most you may need to do is widen the width of your foundation as it touches it.

However, you may have some trouble arguing this with your building inspector, because these methods are not detailed in the Building Regulations Guidelines (mind you, neither are quite a few other common building methods). It's a common misconception that all houses need to have cement-filled trenches as their foundations.

Another low-impact solution is to use pillars or piers instead of a strip foundation.

* Foamglas is a rigid, lightweight and highly insulating material made from recycled bottles – see www.foamglas.co.uk. Recycled foamglass (rfg) is available from www.lime.org.uk or www.womersleys.co.uk. Leca, also known as Optiroc, is lightweight blown clay particles, sometimes used in agriculture for aerating soil.

This disturbs the ground the least (hence 'low impact') and may cost less because it uses less material, but you must remember that the weight of the building has to be carried by something across the gaps between pillars. For a strawbale house this is usually done with a structural timber box beam, which has to be carefully designed so that it is strong enough to do the job we are asking it to do. Another consideration is that this means that the weight of the building is concentrated on several points rather than spread across a whole strip, so the ground below must be strong enough to take these point loads, which may be as much as 100kN/m^2 or more.

Foundations for good bearing soil

See page 62 for illustrations of some ideas for foundations on good bearing soil.

Foundations for other types of soil

The following are options for different soil types, but they can be used on good bearing soil too.

Silty soil (10-15% silt)

This is the only type of soil that is subject to frost heave, although it is almost impossible to know whether you have clay or silt in your soil without some sort of soil analysis. Most soils are not silty, but nevertheless, most modern foundations are designed to prevent frost heave anyway – which adds a lot of unnecessary labour and expense!

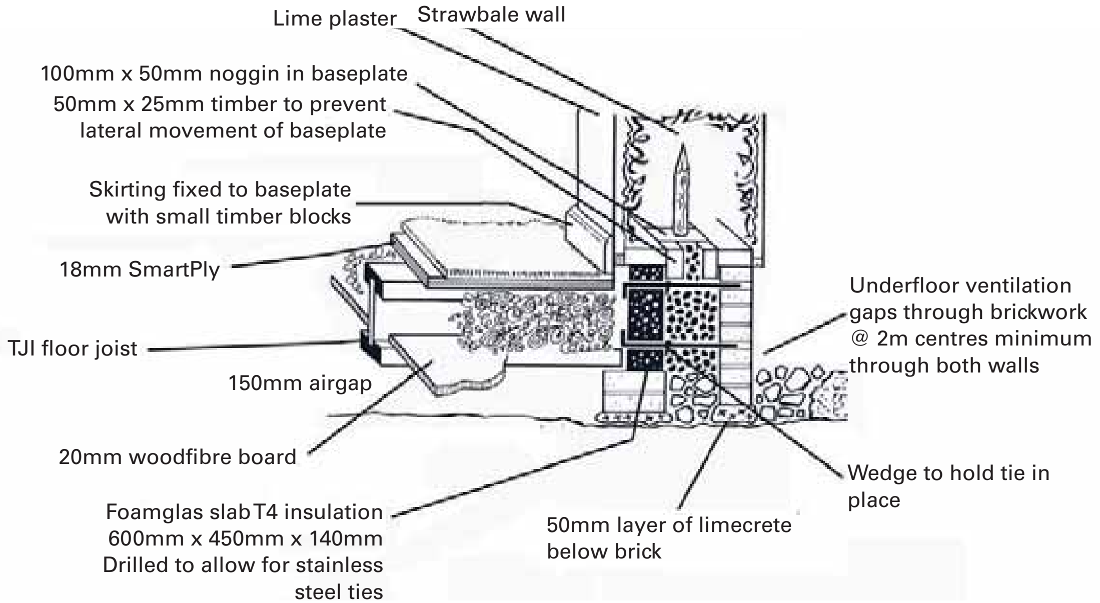
- Any type of strip foundation: extend these to 600mm (26″) deep into the sub-soil. This ensures they are below the frost line and therefore can't be affected by frost heave. In some parts of the country this could be more or less, depending on the level of frost. Your building inspector will know your local conditions.
- Gabions: metal cages filled with stone or recycled brick and concrete. Extend these to 600mm for the same reasons as above. (Illustrated on page 63.)
- Car tyres: really only a version of gabions except that the enclosure is rubber. As above.

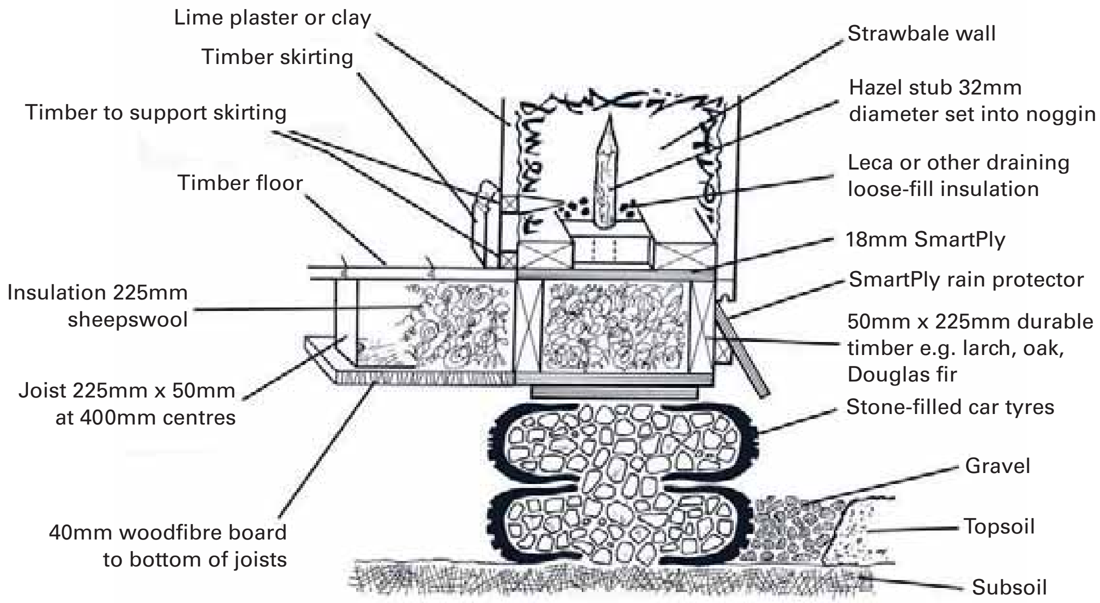
Heavy clay soil

In the UK climate, heavy clay soils are almost always stable because they are always moist. They can move only when the clay is either totally wet or totally dry, and this happens only in extreme circumstances, such as during periods of prolonged flooding or severe drought. Foundation types suitable for clay soils are the same as those for silty soils, plus:

- Rammed stone piles: here a machine pile-drives stone into the ground, many piles are placed for each building, and then the tops of the piles are linked together with something solid. This can be done with low environmental impact by building stone plinths on top and linking the plinths together with a structural timber box beam, or with greater environmental

OPTIONS FOR FOUNDATIONS ON GOOD BEARING SOIL





impact by using concrete piles and a concrete bond beam. Rammed stone piles are a good solution for commercial buildings on heavy clay soils, as the action of ramming compacts the surrounding clay and makes it stronger.

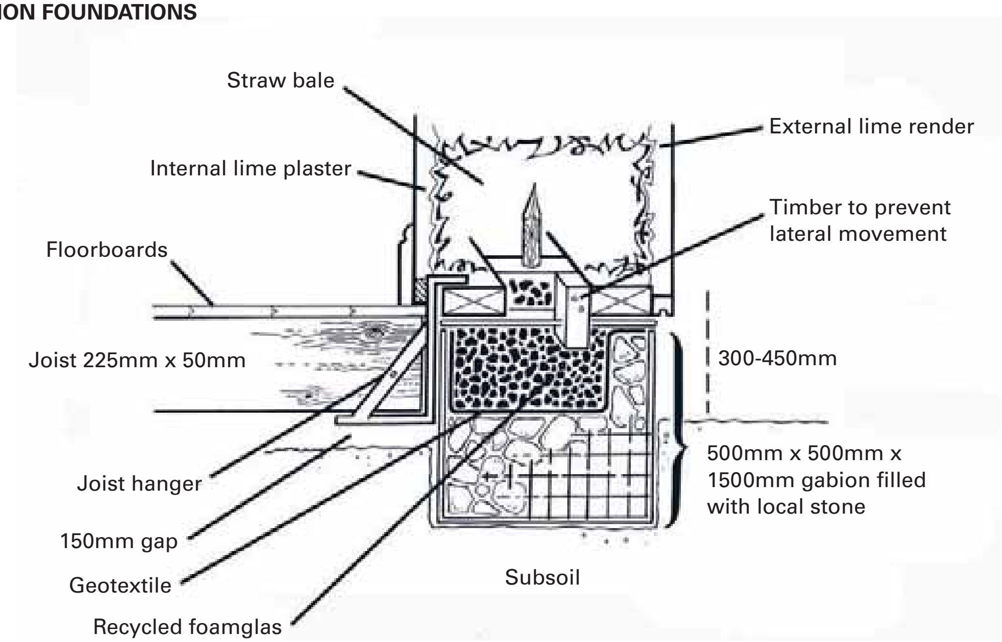
Made-up ground

This describes soil that is of uncertain composition because it isn't just undisturbed subsoil. It may be a brownfield site – one where buildings have stood before. Or it may have been an allotment or landfill site.

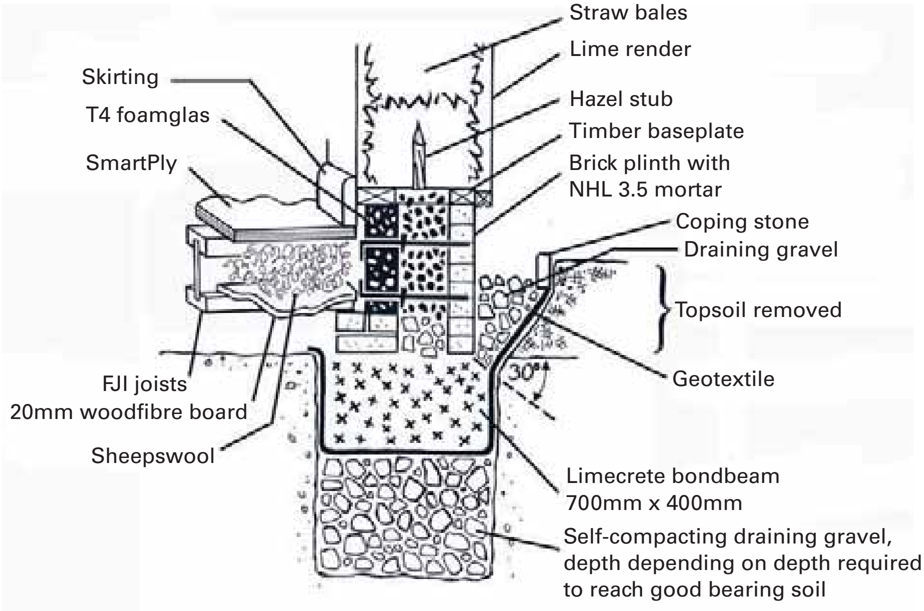
- Self-compacting draining gravel, laid in a trench dug through the made-up ground to the subsoil beneath, with a limecrete cap on top to prevent outward spillage. (Illustrated on page 64)
- Metal screws: similar to the rammed stone piles described on page 61 except using giant steel screws made from mostly recycled steel.
- Gabions. The metal cages can be very useful to contain solid material for a foundation when the made-up ground itself might move.

All of the above solutions will need to be checked by an engineer, and the depth and frequency of them will depend on the weight of the building you are constructing and on what exactly is below ground.

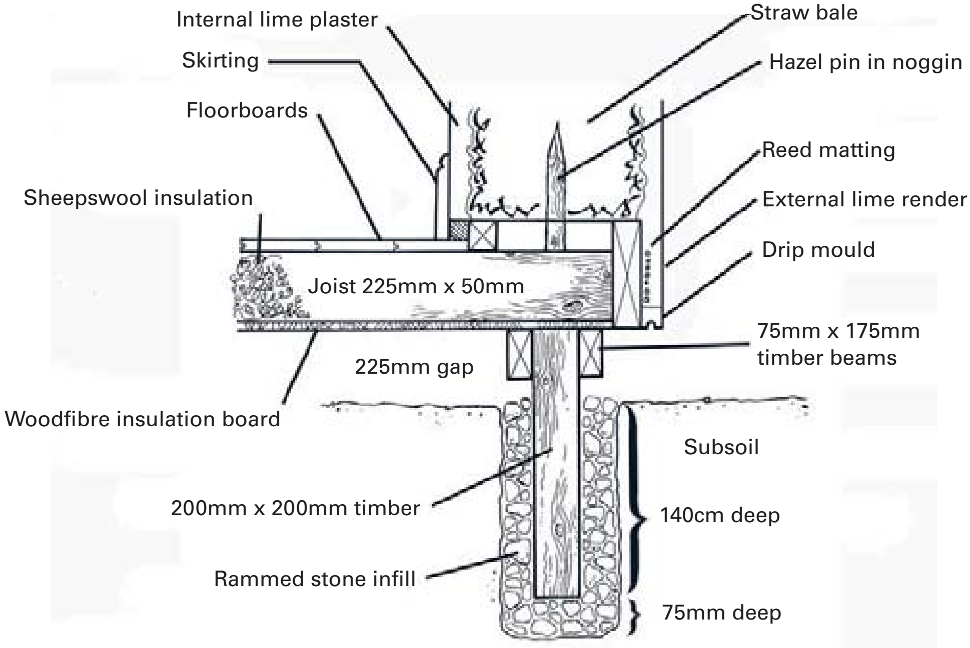
GABION FOUNDATIONS



SELF-COMPACTING DRAINING GRAVEL FOR MADE-UP GROUND



TIMBER PILE FOUNDATION



Wet ground

This might be badly drained, or flood from time to time.

- Stone pile foundations with piers on top.
- Timber pile foundations raised above the ground. (Illustrated on page 64.)
- Raft foundations of timber, e.g. as in Winchester cathedral, which was built on a marsh.

Moving sand soils

As in wet ground, you need to use a deep foundation that carries you below the sand layer.

Sloping ground

Any type of pier foundation is suitable here, or stepped strip foundations.

Other differences in foundations owing to the use of straw

Timber baseplate

Strip foundations will always have a timber base plate on top, and pier foundations will have a structural box beam linking the piers. These provide fixing points inside and out for render stop, skirtings, tie-downs, etc., and also for short hazel stubs on which the first course of bales is imbaled(!), preventing it from sliding off the foundation. The baseplate should also ensure that the straw itself is raised above the finished floor level by at least 25mm (1”), so that if you accidentally drop a bucket of water on the floor the flood won’t touch the straw.

Tie-downs

The foundation design will often need to incorporate some method that allows for the wallplate/roofplate and roof to be fastened down securely to it to prevent the roof from being lifted off by strong winds. If the roof is heavy (e.g. slate or planted) or the site is sheltered this may not be necessary. Methods of tie-down include the following.

- Plastic strapping can be laid underneath the foundations in a U-shaped plastic pipe for protection (25mm water pipe works well). The strapping can then be carried over the wallplate once the straw is in position, and fastened in tension using buckles or similar.
- Strapping can be fixed to the timber baseplate that is laid on top of the foundations, as long as the walls are heavy enough to prevent the baseplate from lifting.

Compression

It will usually also be necessary to fasten temporary compression straps to the foundations. Some ways of doing this are as follows.

- Leave a hole in the foundation through which a metal pin can be inserted later to protrude 100mm (4”) from each face, so

that compression straps can be hooked round them. This pin can be removed after use and the hole plugged.

- Fix anchor bolts into the foundations internally and externally to take compression straps. Ensure that they are fixed close enough to the wall so that they can be plastered in, or that they can be removed later.
- Drill holes in the baseplate large enough to take the hooks of the straps, ensuring that the walls are heavy enough to prevent uplift.

Fixings for door frames, etc.

Anything that fixes directly to the foundation, such as door frames, must have provision made for it. Structural box frames on buildings with solid foundations are usually bolted into the foundation or fixed to the timber baseplate. Fixing posts for windows and doors are fastened securely into the baseplate.

Foundations checklist

The above examples of foundation types have all been used successfully with straw-bale buildings in the UK and Ireland. It is also possible to use these ideas in combination, as long as you follow these basic principles.

- **Raise** the bales off the ground by a minimum of 300mm (12″) but preferably 450mm (18″), and by at least 25mm (1″) higher than the finished floor level.
- **Secure** the bales to the foundations, usually with hazel stubs attached to a timber baseplate.
- **Protect** the bales from moisture from above, below and outside by good design and choice of material.
- Make sure the **foundations are as insulated as the straw walls above.**
- Make provision for **tie-down and compression straps** if required.
- **Use local and natural materials** as much as possible, for the least environmental impact.

Chapter 8

ROOF AND FITTINGS

Wallplate or roofplate

This is a continuous, rigid, perimeter plate that sits on top of the strawbale walls at each floor level and under the roof. It is usually made beforehand in sections for ease of installation, and fixed securely together once in position. The size of timbers used will depend on the loading it will carry from above, the span of the building, etc. They would never be less than 100mm x 50mm (4″ x 2″) in cross section, and can be as much as 225mm x 50mm (9″ x 2″) or even be made out of TJI, FJI or Trus joist. To give this plate structural strength and make it into a box beam it will need to have a strip of board, preferably 18mm SmartPly (because it doesn't use formaldehyde) glued and screwed to the bottom and top. The top plate is added only once the wallplate/roofplate is in position and hazel pins have been fixed down into the bales.

The wallplate or roofplate performs various functions:

- It evenly distributes the load of the roof or floor across the width of the wall, and around the perimeter of the building.
- It provides a rigid perimeter plate that affords compression of the straw walls at an even rate around the whole building.
- It provides a fixing point for strapping or anchors to the foundation in order to hold the roof structure down against wind uplift, and the fixing point for the rafters themselves.

The foundations or baseplate can provide a good template for the wallplate, and it's sensible to construct one on top of the other and place the wallplate to one side for use later. Don't worry if your straw walls don't seem to be quite level once you've finished building – the wallplate will sit on the high points first, compress those, and then compress the rest of the walls evenly.

Make the wallplate sections as large as physically manageable; a well-coordinated team of volunteers can move surprisingly large and heavy objects with ease. The fewer joints you have in this perimeter plate the better, as it will be stronger. Once the wallplate is in position, any distortion in shape that the walls have suffered as a result of their flexibility, or bale frenzy (over-excitement when working with straw!), can be adjusted. The weight of the plate immediately gives the walls greater stability.

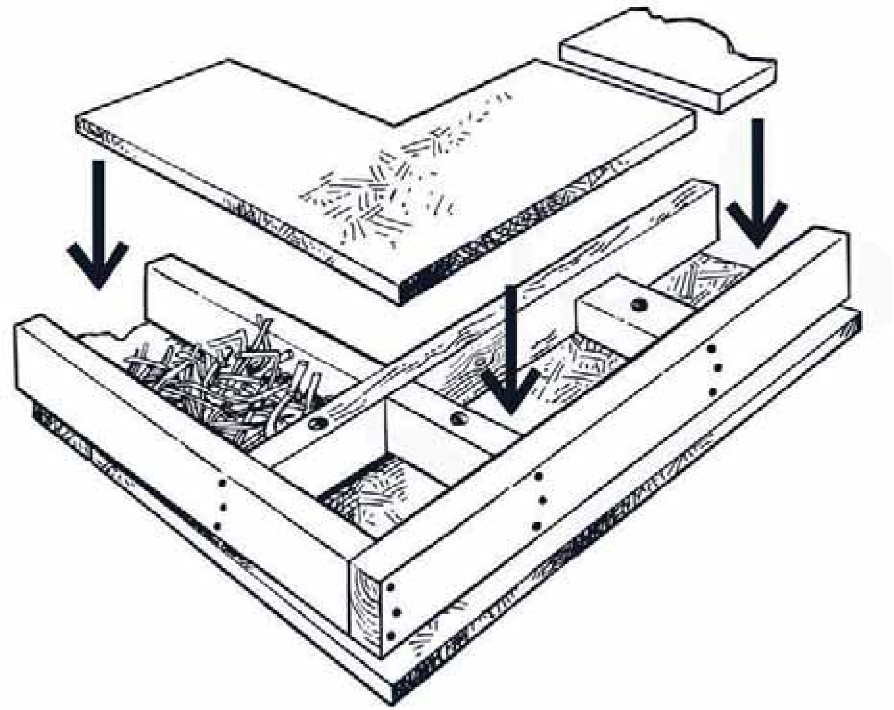
It's hard to describe the transformation that takes place from working on very flexible walls that sway like a ship when you're walking on top of them to finding that most of that movement has disappeared when the plate is placed on top, even before compression.

Beginning at the place of best fit, the walls should be persuaded back into correct alignment if they need it, and the plate pinned down with hazel pins 25-38mm (1-1½") in diameter, 1m (3') long or longer; two pins per bale. Once all the hazel pins are in place the box should be well insulated with tightly stuffed straw or sheepswool and the top plate should be glued and screwed down firmly. This is essential as you must cover the tops of the pins so that any rain cannot possibly hit them and be taken down to the centre of the bales.

Roof

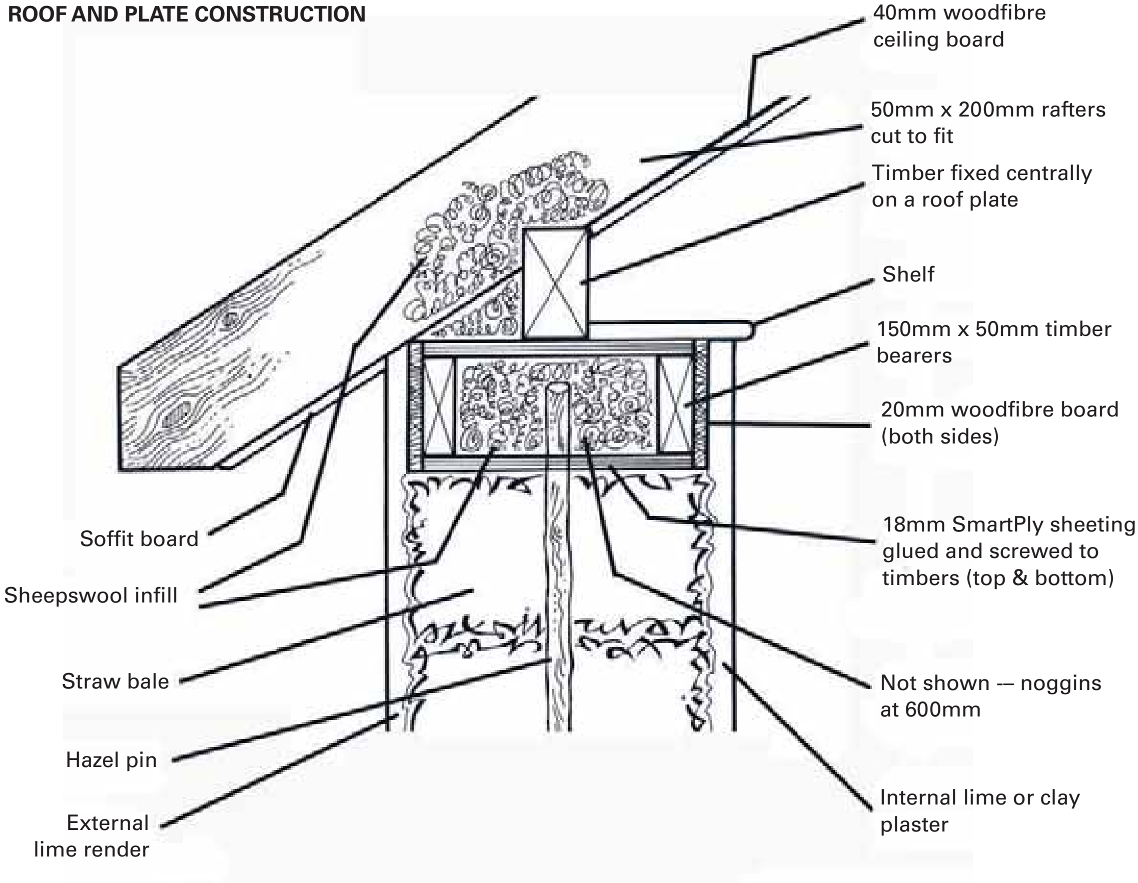
The design of the roof for a strawbale house is not unusual nor particularly different from that for any other building. The main consideration for loadbearing and compressed frame designs is that the loading is spread as evenly as possible around the perimeter

FITTING THE WALLPLATE



walls, across their width, and the load is directed down the centre of the wall. Unlike masonry design, where the roof weight is usually carried on timber placed on top of the inside wall, with straw it is vital that the roof weight is transferred down the centre of the strawbale wall, and not on one edge or another. All loading through straw walls should be vertical as much as possible, otherwise it will tend to knock the walls over. These principles must be remembered during all aspects of construction. Truss rafters should be spread across the walls, not stored at one end of the building before fixing. As the roof is loaded up with slate, tiles, etc., these should also be distributed evenly and not loaded in one spot; nor should half the roof be slated before the other half.

ROOF AND PLATE CONSTRUCTION



Types of roof

The earliest straw houses, built 150 years ago, had hipped roofs. This is a particular design with no gable ends where the roof weight is carried on all four walls. It's a very stable design, very well suited to strawbale houses, because the roof load is evenly spread around all the walls and it means that you don't have unprotected gables exposed to bad weather. This type of roof is far less common now because it's more expensive to build and we live in a society that values low cost more than quality.

More common today is a duo-pitch roof, usually with a pitch of 30° for grey slate, 45° for Welsh slate or tiles and 52° for thatch. Planted ('green') roofs are at a pitch between 10° and 25°, and shingle from 14°. Flat roofs are notoriously prone to failure and should be avoided if at all possible (this is the roofer in me speaking!). You will also see mono-pitch roofs working very well, especially for smaller buildings and extensions. Circular or curved roofs of various pitches are also quite popular designs on many straw buildings.

Roof construction

Originally (that is, several hundred years ago), all roofs were what is known as 'cut roofs', hand-cut from sawn or in-the-round timber. They were pretty heavy and often used whole trees for purlins, king posts and A-frames, with rafters being in lighter, smaller-dimension timber. As the years went by, timber grew scarcer and smaller houses were built, we still had cut roofs but they were now a simple ridge board, usually a floorboard, with pairs of rafters 100mm x 75mm (4″ x 3″) pushing against each other, held together by a crosspiece of 100mm x 25mm (4″ x 1″) placed one-third of the way down the slope, with the rafter ends sitting on a 100mm x 75mm (4″ x 3″) timber wall-plate. Sometimes these roofs had a couple of purlins under the rafters of 200mm x 100mm (8″ x 4″) on either slope, particularly for the heavier roofs, which carried the roof weight horizontally on to side walls of stone or brick.

Nowadays it is far more common to see truss rafters, made of small-dimension timber in a factory and held together with metal ganger plates. It can be much more cost-effective for a self-builder to buy trusses than to build her or his own cut roof. The manufacturer needs to know the location of the house (to calculate wind and snow loadings), the dimensions of the building, the size of overhang, where the bearing weight needs to be (crucial for straw buildings) and any other particular features of the design. From this can be calculated the size of trusses required and a quote for supply and delivery.

All sorts of different designs can be used for the roof, depending on such things as the span, internal walls, open-plan ideas, weight and choice of roof covering, etc. It is usually sensible to get someone with experience to check over your ideas before you build, unless you are copying straight from a tried-and-tested method.

Roof insulation

In the past, roof design did not take into account the need for adequate insulation, and most of our older roofs are difficult

to insulate because the rafters don't have enough depth. In order to get enough insulation into the roof, rafters usually need to be about 225mm (9″) deep, or the insulation has to be placed above or below the ceiling joists. Rafters of this depth are so much stronger that their width can often be reduced to 38mm (1½″) and the spacing increased to 600mm (2′).

Straw can be a cost-effective solution for roof insulation but it is heavy compared with other choices, and ceiling joists or rafters need to be strong enough to take the extra weight. However, it is easy to design the roof so that a bale of straw can either fit between the rafters or sit on the ceiling joists. Straw as part of a compressed and plastered wall is not a fire risk, but extra protection needs to be given to it when used in single bales, as it would be for roof insulation, because the strings are vulnerable if there was a fire and the ordinarily dense bale could become a hazard with no strings, as loose straw is very flammable. Therefore it should have a fireproof coating on both sides – 30mm (1¼″) of clay would do this.

Roof coverings

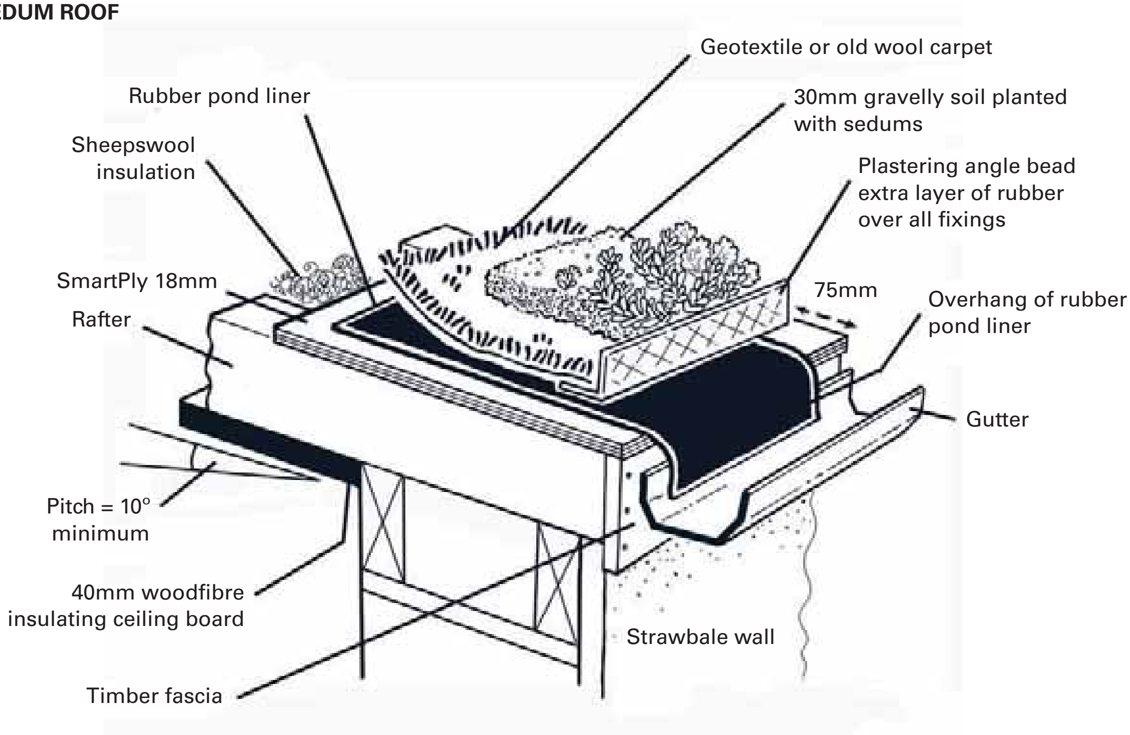
While any type of roof covering can be used, as long as basic design principles are followed, there are some choices that particularly complement a strawbale house because they're more environmentally sustainable.

Cedar or oak shingles has to be one of the best choices, for environmental and aesthetic reasons. They are natural materials and do not require a waterproof membrane such as roofing felt underneath them, as they are breathable and rely on good-quality installation and ventilation for their extremely long life. It is advisable to use a vapour-permeable membrane, however, to protect the rest of the house while it is under construction, as shingling is slow (albeit satisfying) work, and also to act as a wind barrier. When it rains the shingles swell with water, which seals up any possible cracks between them. They hold this water – it doesn't drip through – so the rain itself in the shingles makes it water-tight! It's a bit scary to watch underneath your shingles as they get wet for the first time, until you find out that they really don't drip. They need to be laid with the correct spaces between them, so they can expand and contract with the rain, with a three-layer coverage, (unlike slates, which have only two), and good ventilation so that any moisture can evaporate safely away. Shingles are very compatible with the equally breathable strawbale walls.

Wheat straw (or reed) thatch is also a great choice as a roof covering. Again, it is a totally natural, renewable and beautiful material that should last a long time.

Planted ('green') roofs also complement straw houses, particularly the more modern versions of such roofs, which use only about 25mm (1″) of a gravelly soil, with shallow-rooted plants such as sedum or strawberries growing in them. There are many companies selling different versions of roof build-up for natural roofs, but the design illustrated overleaf is a perfectly good one – the main differences being that it's cheaper and there are no manufacturers' guarantees; its long life depends on the quality and care with which it is installed.

SEDUM ROOF



Overhang at the eaves

Straw houses need a good 'hat' to protect them from the weather. A large overhang is a feature of strawbale buildings, especially in the UK and Irish climate. Just as traditional thatched houses have a roof overhang of about 450mm (18"), so too do straw ones. This gives really good protection to the top of the walls against the rain.

Electricity and plumbing

Here there are no real differences in installation between strawbale and conventional buildings. Electricity cables should be encased in PVC-free conduit sheathing to give extra protection against the (as-yet-unresearched) theoretical risk from heat generated by electric cables sited in a super-insulated wall such as straw. By using a specialist tool like the back of a claw hammer(!), channels can be made in the straw to take the conduit, which is buried in the straw and plastered over. Fixings can be placed wherever required by knocking in a short length of sharpened hazel, just like a giant Rawlplug, and clips, back boxes, cooker hoods, etc. can be attached to these (illustrated opposite). It's probably a good idea to encase back boxes, etc. in clay or lime as an extra fire protection.

Sworders' saleroom

This groundbreaking saleroom was designed and built in 2008 by amazonails in partnership with Melville Dunbar Associates and Collins and Beckett for Sworders Ltd, fine-art auctioneers of Stansted Mountfitchet. A compressive frame design, it is the largest strawbale building in the UK, at 1,100m². It won the East of England Sustainability Award and a Commendation in the International Awards from the RICS in 2009. *Photographs © Rae Parkinson*

Penwhilwr

The 2008 Grand Designs Eco-home of the year winner is another first – the first two-storey loadbearing strawbale house in the UK, built by its owner Rachel Shiamh between 2003 and 2005 with design and build consultancy and training from amazonails. See www.quietearth.org.uk. *Photographs: top © Ravi Freeman, bottom left & right © Bee Rowan, middle © Rachel Shiamh*

Spiral house

This inspiring loadbearing two-storey spiral-shaped house was the first of its kind in Europe, and is based on sacred geometry. It was built by its owner Norita Clesham with Barbara Jones, Bee Rowan and over a hundred volunteers, most of them women, with carpentry help from Willie and Gerard McDonagh. Begun in 2000, it was completed in three years.

Photographs © Bee Rowan


The Footprint Project

The Footprint project is a truly iconic sustainable classroom, with indoor and outdoor space, built for The National Trust at Windermere in Cumbria in 2006. The first strawbale building in Cumbria and the first for the Trust, it is a compressive frame design using timber from the Trust's own woodlands; sheepswool insulation from its sheep; straw, cob and adobe block; and lime and clay renders and plasters. It sits on car tyre foundations. It was built by amazonails and course participants, many of whom work for the Trust, in partnership with Lambert Gill. See www.strawfootprint.org. *Photographs © Barbara Jones*

Shelf Library
Calderdale's first strawbale library extension, at Shelf, Halifax, was designed and built in 2008 by amazonails in partnership with Calderdale Council and Bermar Builders. It won the Halifax Courier Environmental Design Award in 2009. *Photographs © Rae Parkinson*

North Kesteven (left)

North Kesteven was the first local authority to build council houses out of straw, in 2009. These semi-detached houses are designed to meet a stringent brief for affordability and sustainability, and have been built partly through training courses by amazonails, who have also trained the builders, Taylor Pearson. The houses are of loadbearing design with lime render and clay plaster, 85% per cent of the materials are of low embodied energy, and they contain no cement, not even in the foundations. The picture shows the thermally efficient foundations and the floor suspended overhead to provide waterproof covering for the straw. *Photograph © Rae Parkinson*

Ralegh's Cross (bottom)

The world's first semi-detached two-storey loadbearing straw houses, built for Ralegh's Cross Inn on the edge of Exmoor, with a fire wall of plastered loadbearing straw. Built by amazonails in partnership with Quantock Builders, the two three-bedroomed semis contain no cement and are expected to make significant savings on energy bills due to their super-insulation. *Photograph © Barbara Jones*







Agbrigg (top left)
A fine example of a simple allotment building in Wakefield, West Yorks, this has car tyre foundations, loadbearing straw walls, lime and clay renders/plasters, a planted sedum roof and a composting toilet with disabled access. It was built by amazonails in partnership with Dales (Contracts) Ltd. *Photograph © Rae Parkinson*

Summerhouse (top centre)
This beautiful circular garden house is actually very simple and totally sustainable. It has an insulated clay floor, loadbearing straw walls and a cedar shingle roof, and was built by the owners Sue and Richard Nicol with the help of amazonails. *Photograph © Rae Parkinson*

Classroom (top right and middle right)
The first of the strawbale buildings to be constructed at Assington Mill, Suffolk, this classroom has a timber framework and straw infill, and utilises an existing cement slab floor. It is rendered inside and out with local home-made clay plaster except for the gables, which are lime-rendered. *Photographs © Rae Parkinson*

Story Hut (middle, left and centre)
This simple but effective story-telling hut, Assington Mill's second strawbale building, has car tyre foundations, a rammed chalk floor and a thatched roof. *Photographs © Rae Parkinson*

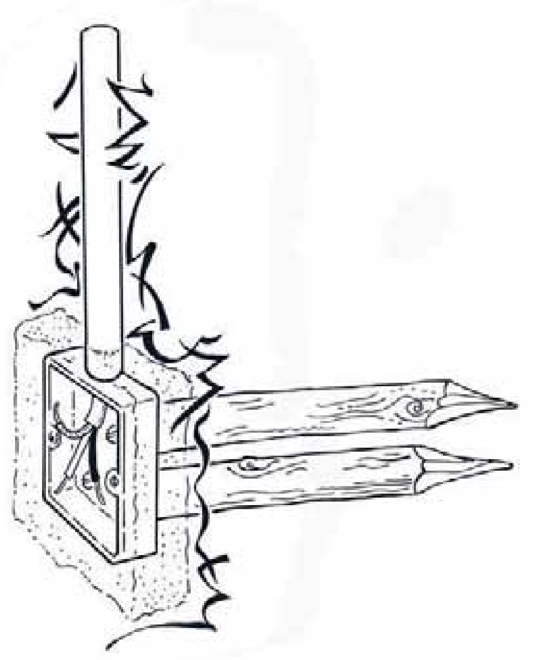
Owlery (bottom)
This two-storey loadbearing owlery was built at Assington Mill by amazonails course particpants in 2008, and completed by Anne Holden and Bob Cowlin. Barn owls moved in in early 2009. See www.assingtonmill.com. *Photograph © Rae Parkinson*

Carol Atkinson's strawbale cabin (top)
This delightful loadbearing strawbale holiday home was constructed on a caravan chassis and moved to its present location in Howden, East Yorks. Built to amazonails standard design, it was the subject of research by Carol for her MSc thesis: see www.homegrownhome.co.uk. *Photograph © Jakub Wihan*

Hackney City Farm (bottom left)
This large compressive frame strawbale extension to Hackney City Farm, London, was completed in 2008. It was built almost entirely by volunteers and project-managed by Emma Appleton, now of amazonails. *Photograph © Barbara Jones*

The Steiner School (bottom right)
The first strawbale building in Ireland, built in 1996 for The Steiner School, Holywood, Belfast, has loadbearing straw walls with brick plinth foundations. It cost £7,000, with volunteer labour and materials donated at cost.
Photograph © Barbara Jones

ELECTRICAL FITTINGS ATTACHED TO LENGTHS OF HAZEL IN THE STRAWBALE WALL



As far as possible, water-carrying pipes should be designed to be fixed in internal, non-straw walls, to minimise the risk of water seepage to the straw in the event of a leak. Water-carrying pipes that pass through straw walls should contain no joints, and be encased in larger plastic pipes for the full width of the wall, just the same as for any other type of wall. An advantage of the deep straw walls is that soil stacks and other non-water carrying pipes can be buried in them and taken up through the roof, instead of the usual unsightly series of grey pipes we often see at the backs of houses. Try not to put anything metal into the straw or plaster and render, as there is a slight possibility that warm water vapour passing through the wall could condense on the cold metal. If you do, wrap it in pipe lagging to protect the straw from it.

Internal fittings

Cupboards, shelves, light switches and sockets, bathroom facilities, etc. can all be fixed by using a sharpened pin of hazel (about 200mm x 32mm; 8″ x 1¼″ diameter) knocked into the body of a bale, which provides fixings for screws or nails. These fixing points need to be placed before internal plastering, but can be added at a later stage if necessary. They should protrude from the bale wall by the thickness of the plaster, about 30mm, but excess can be cut off later, and they can be located after plastering by simply attaching a screw into the end beforehand. It may be useful to add a series of pins in a horizontal line, and attach a timber to all of them before fixing cupboards, etc. on to this; this method is particularly useful for skirting boards as it gives a straight edge to work your plaster to. Alternatively, vertical battens can be attached to the baseplate and wallplate, from which shelves can be hung. In a framed construction, the framing posts can be used as well.

Prefabrication

A strawbale house should go together like Lego, once the straw is in place, and in order to do this absolutely everything that can be made in advance should be – it should either be already on site or waiting to be delivered. One of the major sources

of frustration with self-builds is keeping the straw dry while waiting for the roof trusses or some other vital part of the process to arrive, or, for example, wanting to get on with the rendering before the end of September but the windows still haven't been made. Don't start building until you're sure you're absolutely ready – waiting another couple of months isn't the end of the world if you'd otherwise be spending the same time worrying about your building. There is no substitute for good planning and preparation.

Once everything is in place straw walls can go up remarkably quickly. *Photograph © Press Association*

Chapter 9

WALL RAISING

A lot has changed in strawbale building since this book was first written! Self-builders are still out there pioneering new methods, but now there are also teams of strawbale builders, working with mainstream contractors to install straw walls for council houses, offices, retail units and private homes. The basic principles are still the same, but details and methods have been refined and developed to meet more rigorous standards for quality, ensuring thermal efficiency and durability.

Whether you're building a true loadbearing structure or using some sort of framework, you'll need to prepare your bales first – unless you're just building something quickly to see how it's done, or don't mind about the quality too much. Many bales will need trimming before use, some will need customising to make them fit different spaces in your walls, and all will need choosing for the spot you want to lay them, like stones in a dry-stone wall, as building with bales can be a bit like making a jigsaw.

Trimming bales

The earliest straw buildings in the UK and Ireland did not use trimmed bales very much, but it has become more common now that houses need to meet more stringent standards for airtightness and insulation. If you're not too concerned about these things then it might not be quite so important to follow the guidelines below.

Basically, when you take a normal bale, it may have 'fat ends'. By this we mean that on the ends there's more straw in the centre, between the strings, just where it is most difficult to measure how long the bale is. If you place two of these bales together, obviously the fattest bits will hit each other, leaving a space around the rest of the end of the bale that could allow air to pass through and so reduce the insulation of the wall. **By trimming, we mean flattening off the end of the bale so that as much surface area as possible from one bale makes contact with that of the next.** First, you want to relocate the straw on the bale end underneath the strings from a high point to the low point using hands, if you feel strong enough, or the ends of a claw hammer placed either side of the string. Sometimes a bale has one corner that's lower than the other three, and this method can be very effective in sorting that out. Because you're repositioning the straw, not taking it out of the bale, this will not reduce its compression. Then pull out

any excess straw from the remaining high points, making sure not to catch bale frenzy and pull too much out, leaving the strings loose! Usually the bulging part of the straw is caused because the strings are very tight, so if you're careful, you can take out the excess without taking out any from underneath a string. **Trimming a bale generally shortens its length slightly, so when you're working out what length your bales are don't forget to trim them first.**

Bale frenzy: a sort of over-excitement caused by inspirational moments with straw. Becomes apparent in any group as soon as the speed with which walls go up is grasped!

Customising bales

This describes the method of altering the length or the shape of a bale. Half bales are always needed, because of the running bond from one course to the next used in bale building (as in brickwork). So if you start on the first course with a whole bale by a doorway, then on the second course you will need a half bale to begin again in the same place. Sometimes, if you're working to designs that didn't take the bale length into account, you'll need to make different lengths of bale rather than only halves. And at window openings you may want to angle the end of the bale so that the splay throws light into the room. In more complicated work, particularly where you have to compensate for poor design, you may need to make all sorts of different shapes and sizes of bale parcels!

A handy tool for customising is the custom-made baling needle. There are various different types, but one is a solid cylinder of steel about 5mm in diameter and about 600mm (2') long, with a 100mm (4") handle bent on the end; the other end is flattened and sharpened with two holes drilled through it. It can be made relatively cheaply by a metal workshop.

Baling needles

If you want to cut a bale in half, don't just cut the strings or the whole bale will fall apart! Instead, you need to re-tie the bale into two separate halves first, and then cut the strings. To do this, it's easier and more fun to work with a partner. Take the bale you want to split in half, and lay it on edge on top of another bale you'll use as a table. Now measure out four lengths of baling twine, each one long enough to go completely around all four sides of the smaller half bale you will be making, and then add a bit extra for tying knots. (As the original bale has two strings, so your two new half bales will also have two strings each, making a total of four.) Take two of these strings and thread them through the holes in the end

of your baling needle. It helps to thread them from opposite sides to each other so that a short end of twine sticks out in either direction from each hole.

Ask your partner to steady the bale from the opposite side of the bale from the one you are about to work on, making sure they are not too close so you don't unexpectedly perform body piercing! Measure halfway along the bale, place your threaded needle by the original string at this point and push it into the bale about 25mm (1") to steady it while you sort your strings out. Here comes the tricky part – you need to push the needle all the way through the bale, at right angles to the face, to come out on the opposite side where the string is and exactly halfway along the bale length *without twisting the strings together!* So keep your fingers between the strings as you push the needle through the bale and don't let go until your partner has carefully pulled the ends out of the needle the other side. Because you threaded the strings through in opposite directions, it should be easy to tell which string belongs to which side of the bale. Take the two ends of string that go round one of the halves, and tie a loop in the end of one of them (not a slip knot). Thread the other end of the twine through this and pull tight, but only to measure about a hand's width, (225mm or 9") back from where the twine passes through the loop. Make another loop at this point, in the twine that doesn't already have a loop in it. Now you can tie a sort of trucker's hitch by threading the end through the first loop and back through the loop in itself and pulling tight.

By pulling on the string between the two loops you can get the string even tighter. It needs to be at least as tight as the original string, and if you can get it tighter than that then it means the original strings could have been put on tighter and the bale would have been more dense. Your partner will have been tying an identical knot on the other half of the bale. Now flip the bale over on to its other side and repeat the whole process where the second original string lies, ending up with two tied parcels and (hopefully) slacker original strings ready to be removed. Don't just cut the strings at random, but look for where the original knots are. These are always close to the corners, one above the other. Cut by the knot and pull off the original strings, then you have two more strings to reuse next time. All being well, you should be able to gently pull the half bales apart from each other, and trim the ends as necessary. If the worst happens and you do get the

strings twisted, all is not lost as you can cut one of them and re-tie a new string, as long as you are careful how you handle the bale. Once you're familiar with this method it only takes a few minutes to make a half bale.

Always customise bales to be slightly smaller than you expect. This allows for the tendency, while suffering from bale frenzy, to want to force your new bale into the gap allowed for it, because you've just spent time making it. And, because of the flexibility of straw, this is possible. However, it will almost always result in a distortion of the wall somewhere else, usually at the nearest corner, or in the buckling of a framing post for a window. Do not give in to the temptation to go for speed rather than a snug fit. Watch out for your work partners and encourage them to adopt a calm and measured approach too!

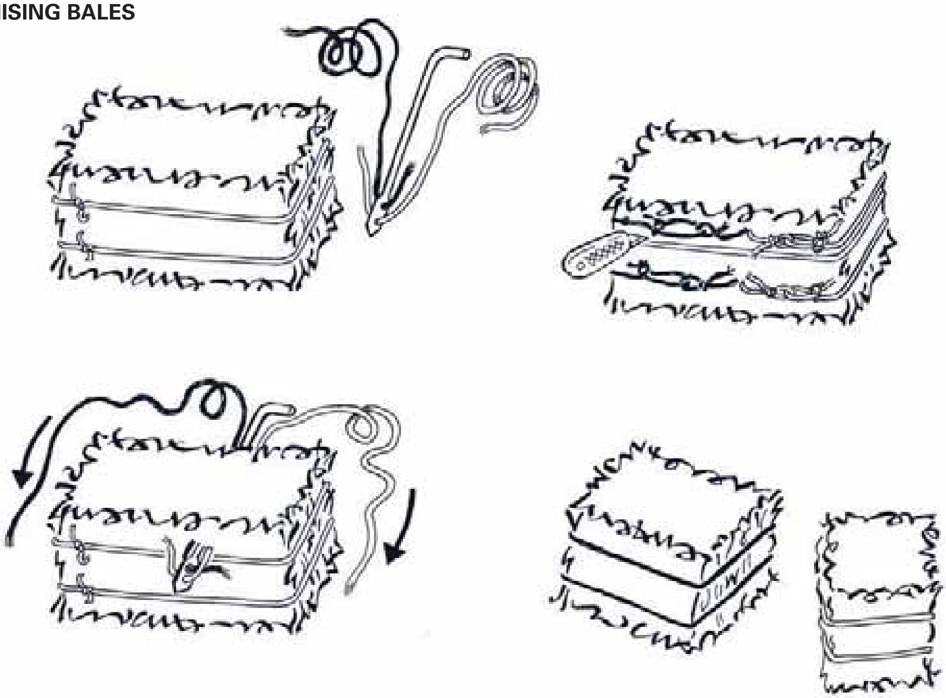
Laying bales

Preparation

Before laying the bales, make sure that everything has been prepared that can be, that all the carpentry is made and on site or is ready to be delivered – including the wallplates, floor joists, insulation, roof trusses, windows and doors, etc. When you begin with the straw you need to be able to build the walls, keep them protected from bad weather and put the floors and roof in place as fast as possible. It's always good to plan and prepare well.

The foundations need to be completed, with a baseplate or structural box beam on top (depending on your choice of foundation) with pre-drilled noggins (cross-pieces) to

CUSTOMISING BALES



take hazel stubs, and insulation between the timbers of the plate. You need to think about how the walls are going to be compressed if you are using pre-compression techniques, and make sure you have made provision for this. If you are using structural door frames they should be fixed securely to the foundations or baseplate before the straw is laid, and any fixing posts for windows and doors also need to be in place. Window boxes, as an alternative, are built into the walls as they go up and are pinned through the base with hazel. For loadbearing buildings, it is useful to place temporary braces at corners and along long lengths of wall to provide a guide to keep everything vertical.

Building

The first course of bales must be placed slowly and carefully, as these provide the template from which the walls will emerge. It is important to make sure that the bale is placed centrally on the baseplate, lining up with the outside edge of the timber, and securely pinned by hazel stubs. You must follow the bale plan accurately, or you might end up with only a half-bale space left in the middle of the wall (which is structurally unsound) as different teams set off from different corners!

Bales go together like giant bricks, a second-course bale straddling equally the joint between two lower bales. Work from fixed points into the centre of each wall; place the corner bales first, and those beside any fixing posts. Make sure that corners are vertical and don't move as more central bales are placed. Use a spirit level! Bales need to be hand-picked to ensure a snug, not over-tight fit.

There are usually some small gaps at the joints between bales, even after the most careful trimming and customising, and these must be stuffed (but not over-stuffed) with straw after every course of bales before beginning the next. And, finally, there is no substitute for climbing on to the bales and jumping hard between the strings! This helps with compression (bales) and depression (humans).

BALE COMPRESSION

Remember to stay calm, work together, and be aware of what other teams are doing on their sections of wall.

Curving bales

Making bales fit the shape of a curvaceous design is a highly technical and difficult part of the job. Care must be taken not to laugh too much. The procedure is to turn a bale on its side, lift one end up on to a log, and jump on it! The middle straws in the bale can be moved fairly easily in relation to the strings – just make sure you keep the end straws in the same place while you move the middle ones, and don't curve the bale so much that the string slips off. That's all!

In order to make very well-insulated walls, you may need to shorten the inside string of each curved bale and trim the ends to form a wedge shape instead of a right angle. This makes a curved bale that fits snugly next to its neighbour without lessening the density of straw at each joint.

Notching bales

If you're using fixing posts at openings, or have a framework, you'll need to notch bales around these to make your building stronger – so that the straw can't slide against the post if there are strong winds pushing against the walls. It also ensures that you don't get a draught between the straw and frame; in other words, it makes your building airtight. The best size of post to use is 100mm x 100mm (4" x 4"), but

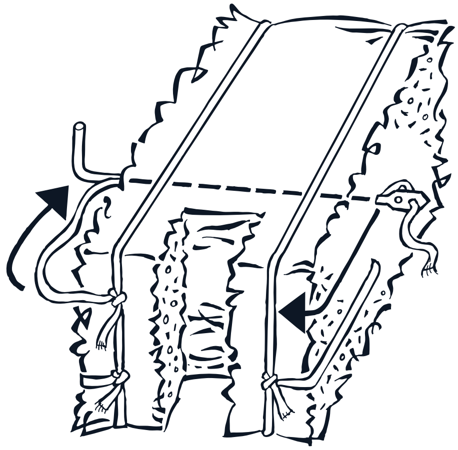
CURVING A BALE

made from two (2″ x 4″) pieces nailed together, as this is stronger and cheaper. These are located in the middle of the bale end because this fits nicely between the strings and a notch can be cut out without affecting the integrity of the bale.

Use a timber template of the same dimensions as your post, stand a bale on end after trimming, and place the template on the bale in the same location as the post will be once finished. Using a sharp saw, cut down beside the template each side to the depth of the timber, then carefully pull out the straw from the centre of the cuts. You'll find that the saw tends to slide off the straw into the centre and you'll need to compensate for this by angling it away from the notch. Also, because of the orientation of the straw, just cutting down like this won't release all the straw; some of it will need to be pulled out from the centre as well. When it comes to fitting, the bale should be held in place horizontally above its final position, and the notch should be held open as it is fitted around the post so the straw from the sides doesn't get in the way of a snug fit.

Sometimes you have to tie the corners of a bale up like a parcel around the window and door openings to stop the strings from slipping into the notch. For this technique, use the baling needle with one length of twine and push through it right through the side of the bale at 90° to the strings, close to the end that is notched, near the corner of the bale and about 150mm (6″) away from the strings. Tie one end of the twine to the string and pull it tight enough to bring the string back from the notch but not so tight as to pull it off the bale! Pull through the other end of the twine and fasten it to the other string, again pulling tight enough but not too tight. Now do the same with a length of twine near the other corner. You should now have a notch between two strings that are securely fastened back from the notch.

NOTCHED BALE



Pinning

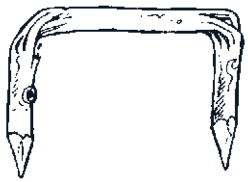
We usually use hazel for this job because it grows in long straight sticks that can be coppiced from the stump every five to seven years without killing the tree. Sweet chestnut can also be used: the choice depends on which part of the country you are in and which tree is most common. What we're after is a tree that has some flexibility but not too much (willow is generally too flexible), grows straight, can be harvested regularly, is durable and relatively cheap; so other trees could be OK too. Hazel has been used since the Stone Age for building, so we're pretty sure of its qualities! Think about wattle-and-daub panels – they are mostly made with hazel or sweet chestnut wattles and have lasted rather a long time.

Stubs

These are short lengths of hazel that are fixed into holes in cross noggins of the baseplate, to secure the first course of bales. The holes are usually 32mm (1¼”) in diameter and the hazel is 350mm (14”) long by 32-38mm (1¼-1½”) diameter. It’s important that the hazel is long enough to only ‘embale’ the first bale and not stick out above it, for obvious rather important health and safety reasons. It should be whittled at the fatter end so that the natural but irregular hazel fits tightly by friction into the regular drilled hole. Two stubs are used per bale, placed centrally, one-third from each end of the bale. It should be possible to see the bale plan by the location of noggins and hazel stubs in the baseplate. Once made, the stubs should not be placed until directly before placing the bale on to them, to avoid vampire-type injuries. Stubs are also used like giant Rawlplugs before plastering, knocked into the centre of a bale wherever you want fixings for sockets, radiators, kitchen cabinets, etc.

Staples

We used to use hazel staples at every radical change of direction, such as at corners, or at delicate points such as where the bales go above windows and need attaching to their neighbours. Nowadays this is done only if the building requires it, such as when the bales are a little less than perfect, or the design needs a bit more robustness. Staples are made from 900mm (3’) lengths of hazel, 25-32mm (1-1¼”) in diameter, by splitting the fibres apart with a heavy hammer at the point where you want them to bend – without breaking – and then twisting and bending. It’s a method used by basket makers and is very effective. You do need to make sure that you have split the fibres enough and that you twist and bend and don’t just belt it then snap it!



Hazel staple

Hazel pin

Internal pinning

Once the walls are four bales high, they need to be pinned with lengths of hazel. Again, sometimes we don’t use these pins at all, but they do help a lot for self-build when people are not too familiar with bale building. Also, they give the wall integrity, so that each bale acts together with the others instead of independently, and this can be very important when building in areas with lots of wind (engineers call this high wind loading). The pins are as long as the height of four bales, less 50mm (2”), which is 1.35m (4’ 6”), and they should be 38-50mm (1½-2”) in diameter, straight, sharpened at the narrow end and without excessive knobbles. There are two pins per bale (dividing the bales into equal thirds), driven down through the centre of the bales to overlap with the hazel stubs that stand up from the foundations. The same length pins are used on the sixth course (unless there is no seventh, in which case they go through

the wallplate instead – see 'External pinning', right) – building up a series of overlapping pins throughout the wall system. The walls of a single or ground floor are usually either six or seven bales high, depending on the design of the foundations and the type of floor installed. First floors are generally from three to six bales high, but can be higher. The same pins but slightly less in diameter are used to pin the wallplate down to the straw. Use a template hole beforehand to make sure that each pin will actually fit through the hole drilled in the wallplate.

Windows and doors

Underneath or above windows you may need to use shorter pins, as there are usually fewer than four bales at this point. Window and door frames can be pinned in sideways to the bales, but only after all settlement has stopped (or the settlement might snap the pins). If you are using fixing posts instead of box frames this won't be necessary.

Pinning for frame designs

All of the above techniques may need to be used for frame methods, as the bales must be stabilised somehow before plastering. However, often the frame prevents the use of pins as there is a beam or a roof over the straw such that pins cannot be inserted. In this case, other methods need to be used. These include fastening some sort of mesh to the posts and pushing the bales tight against it. In the USA this may be chicken wire, but we strongly advise against using metal on the straw and in the render or plaster. The mesh can also be fibreglass or hessian.

External pinning

Here the pins run from baseplate to the wallplate in one continuous piece. (Remember to trim the straw ready for plastering before the pins are put in position – it makes the task of trimming quicker and easier). The pins are placed externally to the straw, again two per bale, inside and outside the wall (four per bale in total), e.g. about 350mm apart and opposite each other. Grooves are cut into the straw with a tool such as the claw on a hammer, so that the pins are flush with the straw. Pairs of pins on either side of the wall are tied together through the straw at each course of bales with baling twine, and are fixed to the base and wallplates with screws or nails. The pins are covered with hessian to provide a key for the plaster, either before or after placement, and can either be hazel, chest-nut, etc. or sawn softwood. This is also a good method if you have really poor-quality bales but want to use them anyway.

Preparing for plastering

This sounds like a fairly innocuous job but can be one of the hardest and most frustrating, depending on the aesthetic finish you require and the quality of your bales. You've done your best to keep the walls straight, you've used the best-quality bales you can find, and you've compressed the walls and put the floors and roof on. Now you need to trim the walls so that you get as flat a surface as possible without all

that hairy straw sticking out. This reduces surface area so that you use far less plaster than you would otherwise; it also reduces the risk of flame spread across the surface of the wall while the building is more vulnerable before plastering. Good tools to use for trimming are a garden strimmer, sharp hedge cutters or clippers, a chainsaw (be careful!) or a crocodile saw. The corners and around windows are usually the only places where strings are exposed, so take extra care here not to break them. (Although, as with everything in strawbale building, there's always a way round it – just carefully tie string extensions to each end and then retie the string.) **It's amazing how transformed the building looks once you've given it a really good haircut!**

Alcoves, niches and truth windows

Add in alcoves and niches at this point. You might want to have a nice little alcove to hold your toilet roll, for instance, or an inset shelf in the study. And most straw buildings have a truth window somewhere (a picture somewhere on the wall that's hinged instead of hung, so that when you open it you can see the straw behind), because once they're finished you can't really tell they're made of straw.

Fixing points for cabinets, shelves, etc.

Think about where you want your kitchen cabinets, light switches, radiators, etc. In all these places you need to add fixing points to the straw before plastering. Short pieces of hazel are ideal for this job: use them like large Rawlplugs. Cut a length of hazel, about 200mm (8") long and 25-32mm (1-1¼") in diameter, and hammer it into the face of the bale at the point where you want to fix something.

Strengthening up round windows and doors

Pay good attention to the shapes you've created around doors and windows. If you had good tight bales then you should be able to shape these with your tools and also provide a sound surface on which to put your first coat of plaster. If not, you'll need to add something to the bales in order to make a good key for the plaster. One way to do this is to make a mix of long straw and lime- (or clay)-rich plaster, and starting at the bottom of the opening work your way up the window or door reveals, building out the edge until you have the required shape. You'll have to leave this a day or so until it becomes hard enough to apply your second coat of plaster. Another option is to use vertical reed matting, fastened tightly into the straw by sewing through from the inside to the outside, or pinning into the straw using barbed hazel pins. You can then apply your first coat of plaster on to the matting. Variations of these two methods can be used above windows and doors, around alcoves and niches, and so on.

Settlement and compression

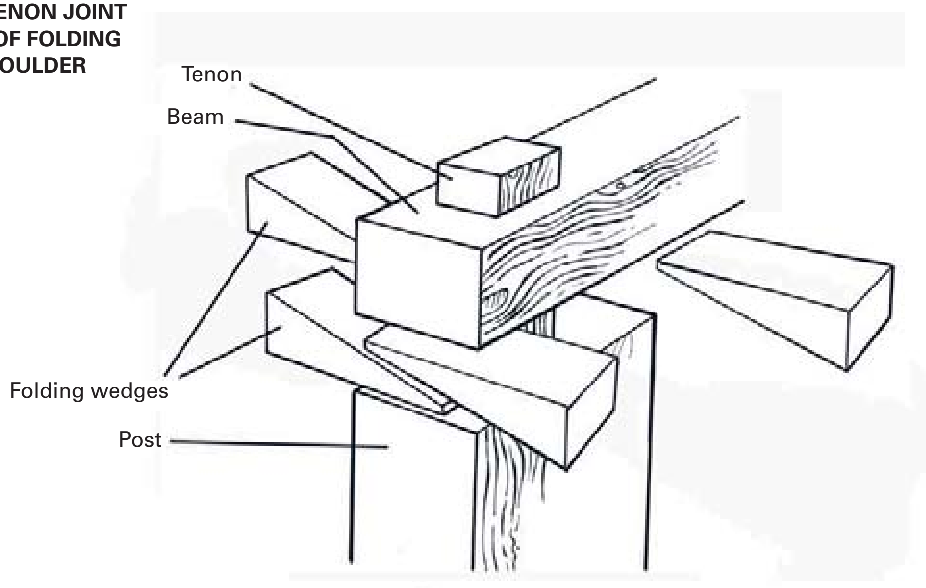
Ideally we would choose the densest bales to build with, in order to reduce the amount of settlement that occurs due to the loading of other bales, floors and roof. Construction-

grade bales will compress up to 10mm (almost half an inch) per bale, whereas more fluffy bales will compress more. Heavier roofs will undoubtedly compress the bales more than lighter roofs. Windows and doors in loadbearing systems should therefore have at least 75mm (3″) settlement gap left above them. During settlement, this gap is maintained by folding wedges of timber with which you can gradually reduce the gap as the building compresses. (Imagine a piece of 100mm x 50mm (4″ x 2″) timber cut along a diagonal line on the wider face from corner to corner. If you now stand these on edge, you can slide one along the other. This has the effect of reducing the height of the timber whilst keeping the edges parallel. This is a pair of folding wedges.) These wedges would be used in all places where settlement needed to occur.

As strawbale building has become more mainstream it has become more common to pre-compress the walls, by using heavy-duty ratchet straps at 1-2m (3′3″-6′6″) intervals along the wall, fastened to or through the foundation, to give even pressure on the walls, and using the wallplate to spread the load across the width and length of the wall (see Chapter 3). **If you have access to lifting equipment, a really great way of creating compression quickly is to lift one-tonne sacks of sand up on to the corners of the wallplate.**

At compression, there is a dramatic change in the stability of the walls, and instead of being flexible stacks they become remarkably solid and reassuring to work on. This is the moment at which sceptical mainstream contractors become infused with bale frenzy themselves and decide they do want to build more strawbale houses after all!

MORTICE AND TENON JOINT SHOWING USE OF FOLDING WEDGES ON SHOULDER



Tie-downs

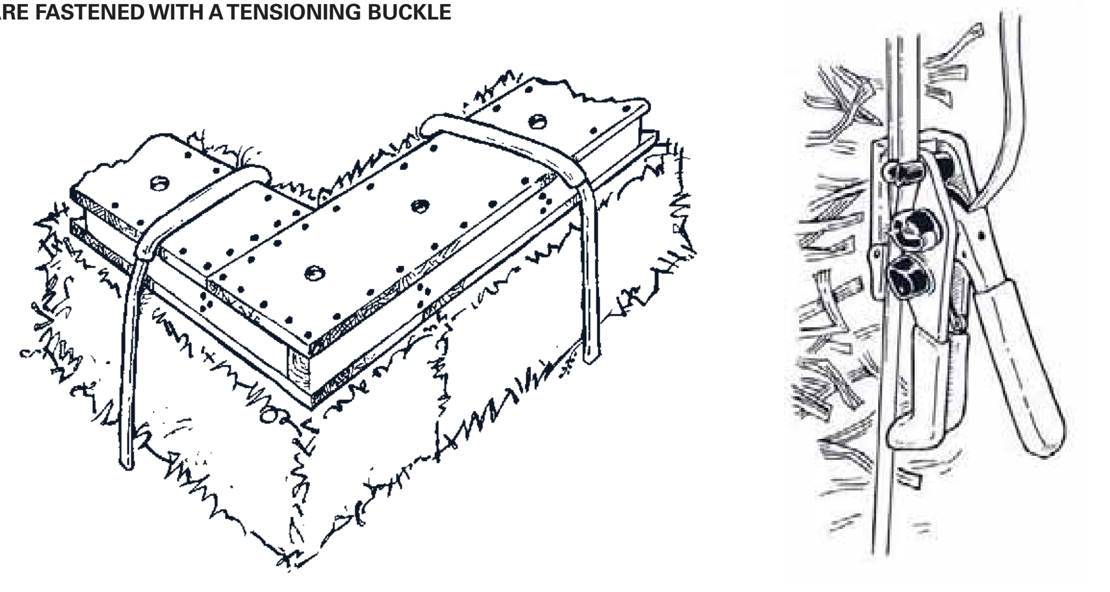
The tie-down has two functions:

- a means whereby the roof structure can be fastened down securely to the foundations, to prevent uplift when subjected to strong winds
- a device to keep the walls in compression while the weight of walls and roof above are added.

Tie-downs, also called strapping, are usually polyester, or sometimes metal with an adjustable fastener so they can be tightened as the walls compress. They can be fixed once the wallplate is pinned down, or can wait until the roof has been constructed. Remember to trim the walls before the tie-downs have been attached, as it gets more difficult afterwards. The tie-down generally goes underneath the baseplate or under the foundations (in plastic piping), up and over the wallplate, and is fastened on both sides of the wall with a tensioning buckle.

Tie-downs aren't always necessary. In two-storey houses, for instance, the ground floor doesn't need to be tied down, because it isn't going anywhere with all that weight on top of it, and the roofplate can be tied down to the first floor. If the roof is sufficiently heavy, there is no need to tie that down at all either, unless you are in an area that experiences high winds. When you plaster the tie-downs in you need to make sure that they are covered really well, either with a wide strip of hessian scrim about 300mm (1′) set into the body coat, or by using long-straw-rich plaster (see page 98) over the tie-down.

TIE-DOWNS GO OVER THE WALLPLATE AND ARE FASTENED WITH A TENSIONING BUCKLE



Buildings with a frame

You'll need all of the above skills and knowledge to work successfully to infill your frame with straw. Ideally, you will have designed your frame to fit the bales, rather than the other way round.

Depending on the type of frame construction, frames can be built off-site and then assembled once the foundation is finished, or built in situ. All framing, including temporary bracing and propping, is done before the straw is placed. The roof is also constructed, with vapour-permeable membrane and battens to provide waterproof shelter, leaving the final roof covering until the straw is in position.

Bales are laid using the methods described previously, on to a timber baseplate using hazel stubs. They are also pinned where possible internally, and externally where not. Usually, bales will be notched around posts so as to make sure walls are airtight and strong, but a particular problem in frame buildings that have not been designed with the straw in mind is that posts are often too large or in the wrong position to be notched into the bales. In this case, hessian about 200mm (8") wide by 600mm (2') long can be attached to the posts and laid into every course of bales to provide friction to prevent the bales from sliding beside the posts in high winds.

It is sensible to create compression on the bales even though they are being used only for infill rather than structurally, and this can be done by using a temporary metal compression plate at one bale below full height, jacking off the beam above with car jacks and inserting the last bale, or adding in a timber compression plate that is strapped down permanently. Whatever method you use, it's important that you stabilise the bales somehow before plastering. See Chapter 3 for more details.

Bales in infill designs can also be laid on edge. They are harder to stack up vertically, and can't be notched very easily because the strings are in the way, but this does reduce wall width by 100mm (4").

Chapter 10

WINDOWS AND DOORS

We need to consider the design of window and door frames and openings for several reasons. We must make sure that they are structurally sound and able to take the loads above them if necessary. We also need to ensure that they are airtight and don't let in draughts, that they are the right size and in the right place to maximise solar gain without overheating, and that they allow enough daylight into our homes and offices.

Loadbearing methods

All window and door openings in loadbearing houses must have some way of supporting the weight of the bales, floors and roof above them, as well as be able to withstand the pressure of the bales wedged in beside and below them. Owing to the flexibility of straw, the use of concrete or steel lintels is inappropriate and their weight in fact would create problems – as they sit on only a small bearing surface they would compress the straw too much in a small area. Weight (load) needs to be spread over as wide a surface area as possible.

Structural box frames

A simple way of dealing with openings is to make a structural box frame into which the actual window frame or door frame is fixed. The design of these box frames must take into account the fact that the straw walls will settle under the weight of the floors and roof above. It is impossible to know exactly how much settlement will occur, as it depends on the density of the bales and the amount of loading applied to them – although it's possible to be pretty accurate if using construction grade bales all from the same source. 75mm (3") is usually sufficient, and the frames are therefore built to be 75mm less than the height of a whole number of bales.

Except in unusual circumstances, structural frames should be multiples of bale dimensions, so external dimensions of the frame could be anything from half a bale to three bales in width and any number of bale heights minus 75mm (3") to allow for compression or settlement.

Frames are pinned into the bales with hazel, through the base during construction, and through the side once settlement has finished. Door frames would not have the

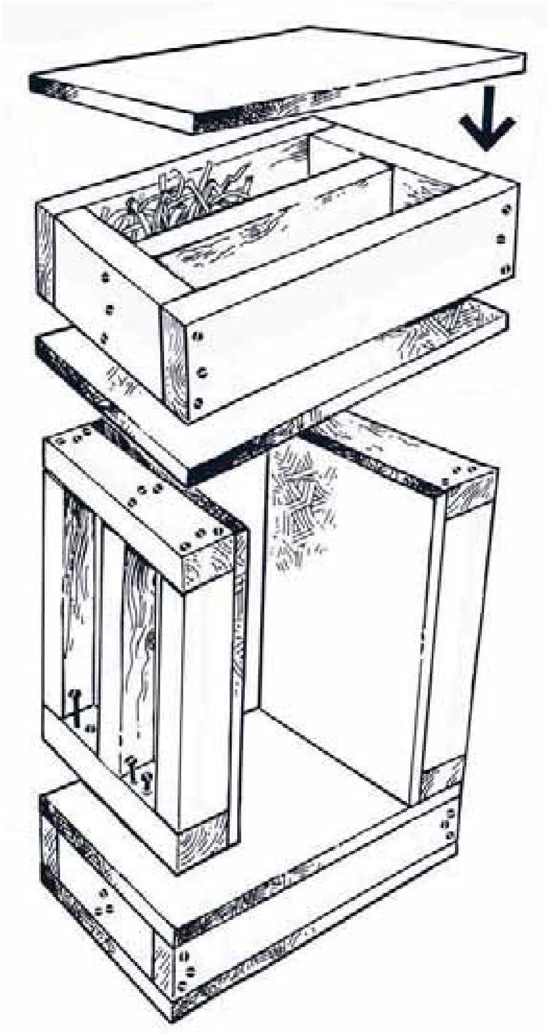
base box as shown (right) for a window. Instead, the sides of the frame would stand directly on the foundation and be fixed in position with bolts into the foundation or attached securely to the timber baseplate.

The actual sizes of timber used, particularly for the top of the box, will depend on what weight the timber has to carry and over what span. This will be affected by the design of the wallplate above it, which may be able to partially act as a lintel for the window or door. In general, an opening of over 900mm (3′) wide will require the box above it to include timber of at least 225mm (9″) high x 50mm (2″) deep to make it strong enough to prevent the box from bending as it carries weight from above across the gap.

Weatherproofing details around windows and doors are very important. The join between the box frame and straw, and between the window frame and box, must be more than adequately covered with plaster and/or timber to prevent draughts and the possibility of rain penetration. Rather than using expanded metal lathing (a twentieth-century solution) we would use hessian, reed mat or woodfibre board* tacked securely to any timber, which can be plastered over to make a weathertight join between straw and timber.

In some cases, the box frame can be attached to the wallplate, using that as a lintel instead of the box having its own top. In such cases, the settlement gap would be left at the bottom of the frame, not the top. However, this isn't a good option if the roof overhang would obscure any light coming in from the top of the window.

STRUCTURAL BOX FRAME



Fixing posts

Increasingly we are using fixing posts instead of structural boxes for the attachment of windows and doors. These use less timber and are easier to work with on larger

* A board made using heat to compress and stick wood fibres together using the wood's own natural lignum, instead of manufactured (and toxic) glues such as formaldehydes.

buildings, as well as providing location points for the wallplate above once it is placed. They are made from two pieces of 100mm x 50mm timber (4″ x 2″) nailed together, which is stronger and cheaper than using a 100mm x 100mm (4″ x 4″) post. They are firmly attached to the baseplate, one either side of each opening, central to the bale wall, bounded on all sides by cross noggins for stability and strength, and left long as they will eventually project through holes in the wallplate. It is essential that these fixing posts are well braced to prevent any distortion of them during building, as bales will be pressed up against them with quite a bit of force. They need to remain vertical and central. The distance between posts would be the width of the actual window or door plus 5mm (¼″) to allow for fitting, plus the thickness of the lining timbers, usually two of 50mm (2″).

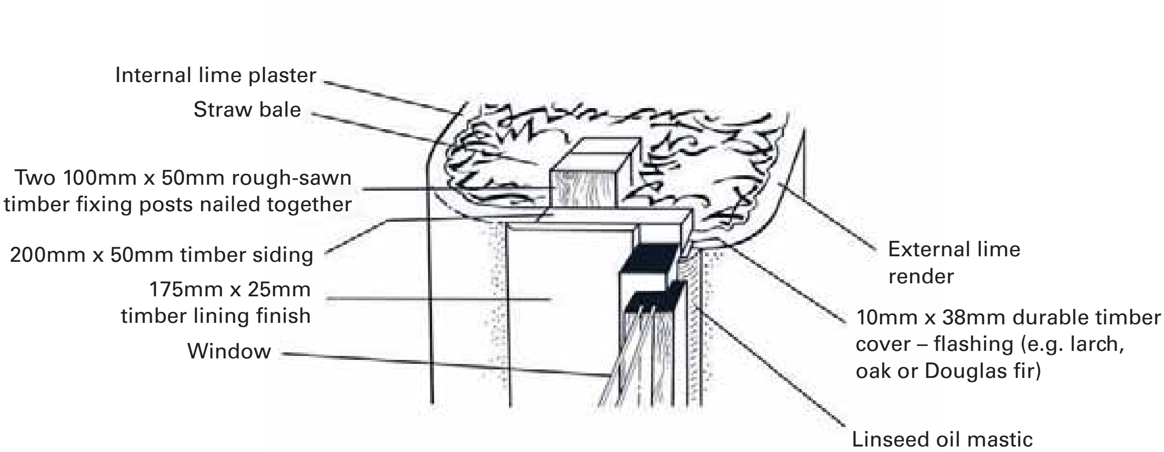
Windows have a timber sill housed horizontally into the posts, 175mm x 38-50mm (7″ x 1½-2″), usually three bales high but this varies according to design. Bales are laid first, pre-compressed manually with straps, and then the sill is fitted; so the height of the sill is calculated based on the number of bales below and the amount of compression to be achieved.

A similar timber is housed into the posts as a header, 300mm x 50-75mm (12″ x 2-3″), and this is calculated to be above the sill by the height of the actual window plus 5mm (¼″) to allow for fitting.

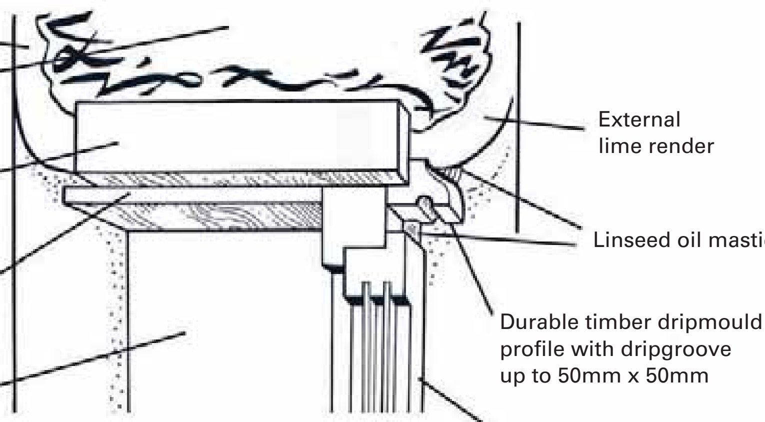
The header must be of sufficient size to take the weight of bales above it without distorting, so for openings larger than 900mm (3′) it will need to be increased to 225mm (9″) high. Instead of using one solid piece, this would be two pieces housed vertically into the sides of the posts instead of the face, with a board above of 300mm x 50mm (12″ x 2″) to support the bales, and below a lining timber. The space between these would be filled with tightly packed straw for insulation.

Doors have a header similar to that for windows, or the wallplate itself acts as the

FIXING POSTS FOR A WINDOW



HEADER TIMBER SLOTTED ON TO FIXING POSTS



header. If this is the case, don't forget about the compression gap for settlement.

Weather protection

The detailing around windows in particular is very important, as the junction between the window, sill and plaster can take a lot of rain and so you need to be especially careful to make sure this is done very well. Carol Atkinson used the design shown overleaf, which adds extra protection at this point, for her windows (this is pictured on page 128). Details for ensuring good weather protection around windows and doors are included in Appendix 4.

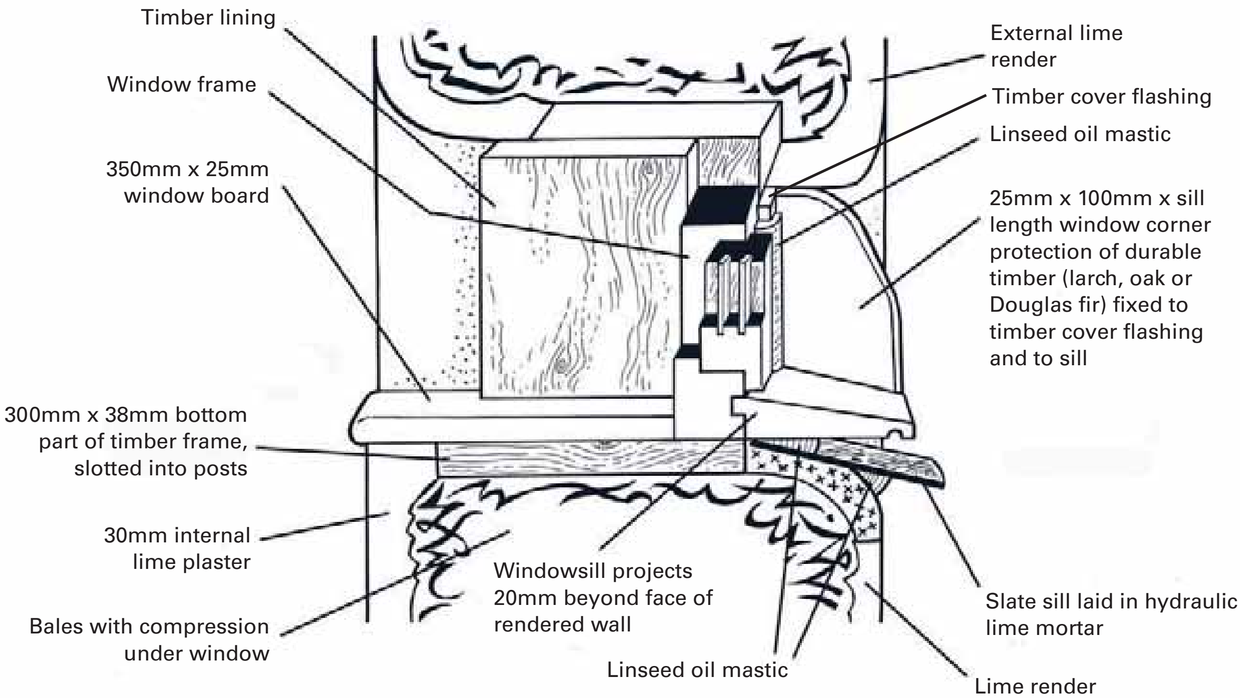
Framework methods

In framework methods, windows and doors are designed into the framing, and usually have upright posts either side of them that run from the baseplate to the beam above. These posts can be of various designs. A timber frame style would use solid timber and a compressive frame would use posts, the design of which was compatible with the method of lowering the frame once all the bales were in position. The framing sill is fixed after the straw below it has been placed and compressed manually (see 'Fixing posts', on previous two pages).

With a framework, the dimensions of windows and doors do not need to be multiples of bale lengths, but the design should ensure that the gap between one fixed post and the next does relate to full or half-bale lengths, to make the bale installation easier.

If there is a bale between the top of the window and the beam above, framing must be designed to carry the full width of the bale, and for compressive frame methods allowance should be made for settlement of the top beam or wallplate on to the straw.

WINDOW DETAILING FOR EXTRA WEATHER PROTECTION



Chapter 11

PLASTERS AND RENDERS – LIME

Straw is a vapour-permeable material: it allows the imperceptible passage of moisture vapour and air through it. If it is sealed by a waterproofing material, it may eventually start to rot. It needs good ventilation around it to stay healthy. In practical terms, this means that anything used to weatherproof or decorate the straw must not impede this breathable nature. The ideal finishes for straw are traditional lime-based plasters or renders, natural clay plasters, or pure gypsum with no additives – since these are also breathable materials – painted with limewash or breathable paints. Both lime and clay are humidity regulators, and help to keep indoor air quality healthy. Apart from them being vapour-permeable, another reason we use lime and clay is that they are flexible – vastly more so than cement or the type of processed gypsum board and finishes we have become used to in modern times, which are classed as rigid materials. Straw and flexible foundations require flexible plasters to go with them: this ensures durability over time, as all buildings move if they stand for many years, and we don't want them to crack! A final reason for using lime, clay or pure gypsum is that they are sustainable, natural materials that are part of a harmonious cycle in nature, and can go back to nature harmlessly at any point in their life; clay especially so.

The ideal finishes for straw are traditional lime-based plasters or renders, natural clay plasters, or pure gypsum, since these are also breathable materials, painted with limewash or breathable paints.

Background to the use of lime

Lime has been used as a binding material (mortar) between stone and brick and as a surface protector of buildings (called render when used outside, and plaster when used inside) for thousands of years. All European countries used lime for building, hundreds of years before cement was invented. In the UK and Ireland lime burning was a cottage industry, with local lime pits wherever there was a source of limestone, and most communities had a working knowledge of its uses and how to produce it. There is no doubt that lime plasters and renders are durable and efficient, well able to do the job of protecting our buildings from the weather.

So, we don't need to argue the case for the ability of lime to withstand the tests of time, weather and functional requirement.

However, in order to use it successfully lime requires thought and understanding of the processes involved in the slow carbonation back to its original limestone. While it is true that a carefully applied lime render or plaster can last for hundreds of years, there have been instances of spectacular failure, and the reasons for these need to be understood if we are not to repeat those mistakes. In essence, the preparation and practice of limework is simple, but variables in the sand, the lime and particularly in the weather during application and drying time have a critical effect on the overall durability of the material.

Traditionally, knowledge about lime was passed down from one generation to the next, and people were used to using it continuously, and so built up a wealth of experience based on a sound knowledge of the material. Today, there are very few skilled craftsmen (we haven't found any women yet) remaining from those times, and we are having to learn as best we can from what we have left, and from remembered histories.

To some extent, this can result in an over-technical approach to what was essentially a practical and rather ad hoc building practice. We are trying to specify exact lime/sand mixes when most likely what happened on site was fairly rough and ready, except for the most prestigious jobs. And mostly, it worked! As tens of thousands of houses in the UK and Ireland, hundreds of years old, can testify. So what follows is an attempt to explain what happens in the lime burning, slaking and mixing process, and what is important to know, so that you can take care of your own limework satisfactorily.

Limestone and lime burning

The raw material for all lime mortars and renders is naturally occurring limestone, shells or coral, which is calcium carbonate ($CaCO_3$). It is made into lime putty by a relatively simple process. Traditionally, the limestone is placed in a specially built kiln (sometimes a pit or a heap) and layered with fuel such as coal or brush and burnt for about 12 hours. It needs to reach a temperature of 900-1200°C; 900°C for carbon dioxide (CO_2) to be driven off, and 1200°C for the heat to penetrate through to the centre of the stone.

As it heats up, steam is driven off first (water, H_2O), which is always present in the limestone, and the following chemical change takes place:

heat + $CaCO_3 \Rightarrow CaO + CO_2$
(heat + calcium carbonate ➡ calcium oxide + carbon dioxide)

At the end of the burning process, calcium oxide in the form of whitish lumps or powder is left with bits of burnt and unburnt limestone. Over-burnt limestone appears as black, glassy pieces, and these should be removed and discarded. The chemical reaction that takes place is usually more complicated than this, due to other carbonates and silicates being present in the limestone, but it's important to understand the basic changes that are taking place at this stage. Calcium oxide, called 'lump lime' or 'quicklime', is very reactive and can be dangerous: it MUST be kept dry as it reacts very quickly with water – even the water in the air or the moisture in your skin – to form calcium hydroxide, which is the first step to reversing the process back

to calcium carbonate again. Just as making quicklime needed heat, the reverse process PRODUCES heat. For this reason, NEVER add water to quicklime – always do it the other way round or it may explode!

$CaO + H_2O \Rightarrow Ca(OH)_2$ + heat
(calcium oxide + water ➡ calcium hydroxide + heat)

So quicklime added to water gives us . . . lime putty!

Lime putty can be ordered from a supplier, ready-made in airtight sacks or tubs, or you can make your own.

Protective clothing, goggles and a mask should be worn when working with quicklime.

How to make lime putty

Recipe: 2 parts water to 1 part quicklime (by volume).

To make lime putty (calcium hydroxide, $Ca(OH)_2$), great care must be taken and protective clothes, mask and gloves MUST be worn, as a tremendous amount of heat is generated, producing steam and spitting lime.

NEVER ADD WATER TO QUICKLIME, BECAUSE IT CAN EXPLODE. ALWAYS ADD QUICKLIME TO WATER.

First, pour water into a metal bath (do not use plastic), twice as much by volume as the lump lime to be used. Two people are needed: one adding the lime and the other raking and mixing. Care must be taken when placing the bath, as the heat generated can burn any grass or wood underneath it. Add some of the quicklime to the water, and immediately rake and mix it: a garden hoe is the best tool for the job. The process of adding quicklime to water is called *slaking*, and great care needs to be taken as the temperature soars and the whole mix starts to bubble and boil.

Slowly add the rest of the quicklime, raking continuously. The purer the quicklime is, the faster the hydration process occurs. Keep on raking and mixing until the lumps have all broken down, and then leave to cool completely. Sieve the resulting putty, which feels like double cream at this point, through a 1⁄16″ grid to take out any pieces of limestone that were not burnt in the kiln, as these will not react. These can go back in the kiln for burning next time. What you now have is slaked lime, or lime putty, which is best stored for at least three months before use. This is to ensure that most of the calcium oxide has hydrated, which takes time. It's important not to expose lime putty to the air, or it will begin to carbonate before you use it. If this happens, the lime will not be as reactive and will make a much weaker mix than you require.

Traditionally, lime putty was stored in a pit in the ground, where it would remain for several months or years before use. The advantage of a pit is that any excess water rises to the top, leaving good-quality putty below. The Romans forbade the use of any lime putty that was less than three years old, and all the old practitioners say that the older the lime is the better it is for the job. Lime putty in pits was a valuable commodity and would often be bequeathed from one

generation to the next. Opinions differ about the quality of lime putty in the presence of frost, although most seem to think this can improve it. The fact that lime was kept in pits for many years, where it must also have been frosted, suggests that this had no adverse effects.

How to make lime render and plaster

Lime render and plaster can be mixed on site from lime putty and local sand, or sometimes from quicklime and sand, depending on local availability. Well-graded sharp sand can be bought from a builders' merchant, but keep it clean. If you prefer not to make your own plaster or render, it can be bought ready-mixed from one of a growing number of suppliers.

Lime putty render mix

Recipe: 1 part lime putty to 3 parts sand.

The sand MUST be well graded, that is, contain particle sizes ranging from very small (dust) to quite large (5mm or 3⁄16"), and these should be angular ('sharp'), not rounded. When compressed together, the aim is to use as much lime putty as necessary to fill the spaces between the grains (the void spaces) but no more. The mix is almost always 3 parts sand to 1 part lime putty (3:1), because the void spaces take up about 33 per cent or ⅓ of the volume of most sands.

The only real difference between a plaster (for inside work) and a render (for outside work) is the fineness or coarseness of the sand used. Render for areas that experience lots of wind-driven rain may contain aggregate particles up to 10mm (⅜") or so in size; but inside a smoother finish is usually preferred, using a sand of smaller grain size.

The longer a lime putty has matured, the more solid it becomes, and the better render it makes. It may seem hard to work at first if it has been maturing a long time, but by pounding and beating it with wooden mallets or posts it soon becomes more plastic and can be worked into the sand. This beating part can be VERY labour intensive, but should not be missed out. Because it's so hard to work, it can be easier to mix the sand with fresh lime putty, which doesn't need beating, and then leave this mix to mature for three months, traditionally under a thick layer of sacking and then straw!

Hot lime render mix

Recipe: 2 parts quicklime powder to 9 parts sand.

This is probably the most common method used historically for mortars. In this method, the quicklime is added to *damp* sand in a bath and mixed with a shovel. Very soon, the mix starts steaming and becomes warm, as the reactive calcium oxide hydrates with the water in the sand. At this point, the mix can be riddled (passed through a sieve, usually 6mm (¼") for renders), to get rid of any unburnt or over-burnt limestone, as it's easier to do this when the quicklime has dried out the sand. This process is dangerous because the powdered quicklime blows in the air and can get into eyes and lungs, reacting with the moisture there; plus the mix gets hot very quickly and may

be difficult to control. It must be raked and mixed continuously and, depending on the dampness of the sand, may not need any extra water adding. You are aiming for a mix that is nice and sticky; workable, but not sloppy. It should ideally be left overnight before using.

What happens to lime render when exposed to air

It's essential to understand the chemical change that starts to take place once the render is exposed to air, in order to know how best to care for it. Once it's on a wall, it begins to carbonate: a chemical process begins whereby the carbon dioxide starts to change the calcium hydroxide back into the original limestone (calcium carbonate).

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$
(calcium hydroxide + carbon dioxide ➡ calcium carbonate + water)

This change happens very slowly – some renders are hundreds of years old and even now not all of the calcium hydroxide in them is carbonated. Also, the change can happen only in the presence of water. The carbon dioxide must be in solution (dis-solved in water), as some of it always is in a humid atmosphere, but *too much* water inhibits the process. It can take a pure lime-putty/sand mix several days to harden, which does NOT mean that all the lime is carbonated – this process will continue for months or years afterwards. The ideal conditions for a lime render are high humidity and good ventilation.

How to use lime render and plaster on straw

The internal and external faces of the straw walls should be given a very short haircut –trimmed down to a neat finish. All the long, hairy, unkempt bits of straw should be removed.

The reasons for this are:

- to reduce the amount of plaster/render required by reducing the surface area
- to even out any large undulations in the surface of the wall
- to minimise flame spread over the surface of the bales, in the event of a fire before plastering.

If you are making your own plaster or render from putty, it should be stored in a trench or pit for a minimum of three months, covered with sacking and straw. Alternatively, it can be stored in airtight buckets. The lime mix should be applied directly to the trimmed straw.

There is no need to wrap the straw in stucco or chicken wire first, as many cement-rendered buildings in the USA have been. This is totally unnecessary and a waste of time! Both lime and clay stick extremely well to the straw, particularly if applied by hand or sprayer.

The lime plaster or render should be beaten and worked to a stiff consistency, so sticky that it can be held upside-down on a trowel. There should be no need to add water to it, as this would increase the risk of shrinkage

cracks. It will generally become more plastic with lots of beating! Traditionally this was a completely separate trade, being a lime render beater. These days, render can be knocked up in a paddle mill (used by potters) to save all that work by hand. Generally, a cement mixer WON'T do the job, as the mix stays in a lump and knocks the machine over; then the tendency is to add water to soften it, and the resultant mix will crack due to too much shrinkage. If the render has been matured by the supplier and then delivered, the vibration caused by the delivery lorry can be enough to soften up the mix. In this case, it may be possible to use a cement mixer to complete the process.

The first key (or scratch) coat on to straw is usually lime-rich to make it stickier, often a 2:1 sand:lime mix. The next two coats of plaster or render contain cow or goat hairs, or chopped fibres such as straw or hemp, well-distributed throughout the mix, to give it much greater strength – in the same way that straw is used in mud plaster to give it tensile strength.

Whilst applying the key coat it will almost always be necessary to fill out some of the undulations inevitably left in the straw after building. This is done with a mixture of long straw, often left over from customising bales, mixed up with the key coat lime mix so that each straw is completely coated with lime, like salad tossed in dressing. It's called a 'long straw mix' for obvious reasons! Because of the straw in this mix, it can be plastered on to the bales in fairly thick (up to 30mm, 1¼") layers, so any hollows or spaces can be filled in quickly. In this way the walls can be flattened off as part of the key coat process, so as not to use too much of the second coat for this purpose.

For strawbale walls, it's usually best to apply the first coat of lime by hand (with gloves, as it's caustic!) because it's more fun, and because the straw tends to flick the stuff back at you if you try to use something like a float. It is not a good idea to use a steel float on a lime render, as this polishes up the surface and closes up the texture, thus preventing humid air from penetrating into the body of the render.

For strawbale walls, it's usually best to apply the first coat of lime by hand (with gloves!) because it's more fun, and because the straw tends to flick the stuff back at you if you try to use something like a float.

It needs to be well rubbed in, to get a good key (join) between the straw and the lime. It's important to encourage the render to cure (go off) from the inside out, not to let the outside skin carbonate too fast: the way this is done is to keep the whole thing MOIST (not wet). The surface should not be allowed to dry out; it will naturally take two to seven days before two-coat render feels hard. The first coat should be as thin as possible, leaving stubbly bits of straw sticking out, and will probably be ready for the second coat on the next day, unless there are pockets of thicker mix in places. A rule of thumb, literally, is to put the second coat on when the first is hard enough that you cannot push your thumb into it. Wet the walls down with a mister, not a hosepipe, before putting the second coat on, and work it well in, either with hands again or a wooden float. Keep the render or plaster damp by misting it, unless you have ideal drizzling weather! It is often not necessary

to do much misting indoors for a plaster, as the wind and sun don't dry the interior air in the same way as they do outside. Keep going over the wall with a wooden float, rubbing in the mix and misting it. **It is probable that lime renders on strawbale walls will carbonate to a greater depth than on stonework, because the straw itself is breathable, and so the back as well as the surface of the render has access to the air.** Usually lime coats are limited to 10-12mm (⅜-½"), as on most surfaces a greater depth would not carbonate fully, but we think this can be increased on straw.

Aftercare for lime renders

Over the next few days, protect the render from direct sunlight, driving rain, forceful wind and frost. Often this can be done by hanging sacking from scaffolding, and keeping it moist to create a humid atmosphere close to the lime. The render may crack, and needs to be reworked several times over the next few days to squeeze and compress the sand particles together, before the surface hardens. The cracks are caused by shrinkage as the excess water in the mix evaporates. The aim is to compress all the render so that there are no air spaces left. The misting is not to add water to the render, but to make sure that carbon dioxide can be carried into the thickness of the layer via the medium of water. It needs to be protected from frost for about three months, so exterior lime renders should be applied only between the end of April and mid-September, unless the local microclimate is frost-free for longer.

Internal plasters can be applied at any time of year, as frost is unlikely to attack them inside. However, no render or plaster will carbonate if the temperature drops below 8°C, and although this will not damage the plaster/render, it will mean that it takes longer than the usual three months to carbonate. Internal walls plastered in winter in an unheated house can still be soft to the touch three months later. This then poses the question of whether it would have been more sensible to wait till spring.

Dry-hydrate lime mixes

Type N and Type S

The bags of lime bought at a builders' merchants are almost always hydrated lime, which is quicklime that has been factory slaked (added to water) only so much that a powder is formed and not putty. It makes a substance that is far less reactive and dangerous than quicklime, but also does not have the same properties as lime putty or hot lime mixes, usually because less care has gone into its production and it has sat on a shelf for too long. Whereas in the UK and Ireland hydrated limes are made from quite pure limestone, in the USA most limestone is 'dolomitic', which means it has a proportion of magnesium carbonate in it. This is simply due to different geology, and although it means that greater care must be taken when working with dolomitic lime, it can produce very good results. The US hydrates are called Type N or Type S. As a general rule it is wisest to use Type S hydrate, because this has been autoclaved (slaked by steam under pressure) to make sure that all the magnesium oxide, as well as the calcium

oxide, has been slaked. Type N hydrate must be made up into a putty and stored for a while to make sure that all the magnesium oxide has slaked, as it takes longer for magnesium to slake than it does for calcium.

Why dry-hydrate renders can fail

There are several reasons that renders made from bagged (dry) hydrate often fail. The lime may have been either over-burnt or under-burnt (or both); it may not have been completely slaked, leaving lumps of calcium oxide; or it may have been stored for too long before use, so that an unknown quantity of it has already carbonated and it therefore becomes useless and unreactive. For the purposes for which bagged hydrate is used today – as an addition to cement mixes – none of this matters too much. Some of the French bagged limes have been found to contain either pure chalk (a type of limestone) or other impurities, such as white clay, as well as the calcium hydrate. Obviously, this means that for every part of dry hydrate used, only some of it will be able to carbonate. When made into render or plaster it may therefore contain a lot less lime than expected, and it is hard to be sure, without chemical analysis of each bag, exactly what the proportions are. Since it is only the lime that forms the binder between the sand particles, using impure dry hydrate can have the effect of increasing the amount of aggregate and decreasing the amount of lime – so that if you used a 3:1 mix it may actually be 4:1 or 5:1. In practice, a 'lean' mix (insufficient lime binder) causes the render to become powdery in places, which decays over time as it is more prone to damage from the weather. The presence of unslaked lime in the dry hydrate can cause 'popping' of the surface as the calcium oxide reacts suddenly with water (rain) and explodes, leaving a pockmark in the wall.

How to make lime renders from dry hydrate

If you do want to use dry hydrate, follow these guidelines.

1. Always use fresh hydrated lime, less than one month old if possible. The date of manufacture should be on the bag.

2. As far as possible, check the production process and buy from a reputable company, although this still doesn't guarantee the quality of the product!

3. Make up the hydrate into a lime putty by putting it into a bucket and adding water. Stir well, and add only enough water to make a very stiff mix. Leave it for 24 hours, and then make up a lime render as for a lime putty mix (see page 95).

4. If you think your dry hydrate is not quite pure calcium hydroxide, use this recipe to compensate for the extra aggregate: 2½ parts sand:1 part lime putty. If you have reliable information that your hydrate is pure, then stick to the original 3:1 mix.

5. Once mixed up with sand, use in the same way as any other lime render.

Limewash and decorating

Limewash

Limewash is made from lime putty, diluted with water. Applying limewash to the building once it's been plastered or rendered should be seen as part of the plastering process. If there are any tiny cracks left in the finished plaster, the limewash will seal these up. Limewash is very thin and watery, and should be applied in many thin coats, left to dry overnight each time, but because of this wateriness it is much quicker to apply than ordinary paint. Putting it on too thick can make the surface powdery. Over time, lime plasters have a self-healing effect. Any cracks that do appear tend to close up as the lime carbonates, because the calcium carbonate molecule is bigger than the calcium hydroxide one.

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Externally, walls that take a lot of weather, usually the south-west side, should have about five coats of limewash to protect them. The rest of the building may need only three, although the more coats you apply initially the better the weatherproofing will be. How frequently the walls need re-coating will depend on the weather, varying between once-yearly and five-yearly. (In feudal England there was a tradition of limewashing houses on May Day each year.) Natural pigments can be added to the limewash, giving a large range of beautiful colours with a visual quality that is quite different from modern vinyl paints. Limewashes are more variegated; less stark and uniform. Lovely!

Active silicate paints

These are waterglass natural mineral paints that bond with the silica (sand) in the plaster or render and are an alternative to limewashes. It's very important to use an active silicate paint, and to make sure that it does not contain any synthetics (good examples are Beeck and some of the Keim products), otherwise the paint will not be vapour-permeable. These paints differ from the limewashes in that the colours are uniform, not variegated, but they also provide much better weather protection and durability and are recommended for exposed buildings, or those where regular maintenance may be a problem, as they do not need to be reapplied for about 15 years, unless you get fed up with the colour!

Maintenance of lime renders and plasters

As long as a lime render is regularly lime-washed, or has had mineral paint applied, there should be no other need for mainten-ance unless something else is causing problems, such as a broken gutter or an overgrown garden. Otherwise the render behaves much like straw, in that if you let it breathe, it will take care of itself. Lime renders should be limewashed every two or three years at first, and you may need to do it once a year on the most exposed wall, but as time goes on the need for this is reduced as the render becomes stronger, more like the limestone that it came from, and

limewashing becomes a surface decoration rather than a protection.

If you do need to patch in a section of render for any reason, take out any loose material, dampen down the surface of the hole, and apply fresh render in thin layers no more than 12mm (½″) thick, working well into the sides. The patch will adhere well to the rest of the render because it's all the same stuff. Limewash over the top when done. Old render can be pounded up and used as well as or instead of sand for aggregate in a new mix.

Hydraulic limes

These should not be confused with hydrated limes (see page 99), although they also come in a bag as a white powder. Hydraulic limes have a 'set' like cement does; that is, they go hard to the touch before they have carbonated. A feebly hydraulic lime (the traditional terminology for a weak hydraulic lime) may set in two days, but an eminently hydraulic lime (a strong one) may set in a few hours. The set is not the same as carbonation, and these limes will still carbonate over a long period. Eminently hydraulic limes are used for such things as the building of lighthouses and bridges, because they will set under water and are not affected by being in water, and also for limecrete floors (see opposite), because of their strength. Some of the strongest of them are known as Roman cements, but they are not the same as what we call cement today.

Hydraulic limes are made from naturally occurring limestone, burnt in a kiln just like other limestones, but it is limestone that contains a lot of clay and aluminium silicates. These 'impurities' give the lime the setting quality, depending on the amounts present. It is possible to create artificially a hydraulic lime by adding what are called 'pozzolans' to pure lime, so-called because the Romans first discovered it by adding ground-up volcanic dust from a place in Italy called Pozzuoli. Many different cultures around the world have used lime renders and mortars, and have added their own pozzolans: ground-up brick dust is a favourite that works well. (Clay alone would not work, because the clay minerals need to be burnt at high temperatures first).

Hydraulic limes on the whole are not suitable to use on strawbale buildings because the set makes them too rigid (like cements) and their breathability is also reduced. Many builders are tempted to use them because they seem to be more like the cement that they are used to – because they are powdered – but in fact they have very different properties. They are sold as NHL (with a number), which stands for natural hydraulic lime, and they come in three strengths: NHL 2 (feebly hydraulic), NHL 3.5 (moderately hydraulic) and NHL 5 (eminently hydraulic). The higher the number, the stronger the lime. The only naturally occurring hydraulic lime available in the UK is manufactured by Singleton Birch in Lincolnshire, made from a Blue Lias limestone, either NHL 2 or NHL 3.5. St Astier, a French company, and Castle, a German one, import their hydraulic limes from France into the UK and Ireland and offer all three strengths.

Hydraulic limes would be used below damp-proof course level and above the eaves, and fat limes (made from putty) elsewhere. In

general, the weakest limes are used for the softest substrates, e.g. NHL 2 on sandstone; and the stronger ones, e.g. NHL 3.5 or NHL 5, on harder backgrounds, such as granite, and where the weather conditions are more severe or for buildings under water. The NHL 2 limes are reasonably similar in properties to the fat limes, and may therefore sometimes be used on strawbale buildings in certain circumstances. For example, they may be applied very late in the year, since a set as well as carbonation would allow a little more protection against frost; or the reason might simply be that it is cheaper to buy bags of lime and mix them yourself with sand and water than to use a ready-mixed fat lime render.

Limecrete

This is the name given to solid floor slabs or bond beams made using NHL 5 lime rather than cement as a binder. Lime has been used in this way for thousands of years, but the knowledge of its use has been almost lost due to the dominance of cement and concrete in the construction industry. However, it has been brought back into use by companies such as Ty Mawr in Wales (see www.lime.org.uk) and adapted to changing demands by adding particular aggregates to the mix to provide solid floors that are also insulated. The following is a method for making a DIY limecrete floor. Because different sands have different strengths and properties it is not recommended that you make a limecrete floor on a large scale without expert advice from companies such as Ty Mawr. Limecrete is usually laid in depths of 100-150mm (4-6″); thinner layers (50-65mm, 2-2½″) can be used (called screeds), using finer aggregates for different surface finishes, or to contain under-floor heating pipes. Advantages of a limecrete floor are a lower environmental impact, no need for expansion joints, and a breathable floor. However, at the moment it is unlikely to cost less than a cement floor because the materials are not yet mass-produced.

The basic recipe is 1:3 NHL 5:well-graded sharp sandy aggregate, 20mm down (meaning the largest gravel in the aggregate is 20mm or ⅞″), using the strongest hydraulic lime.

All quantities are measured by volume. It is very easy to use too much lime as it easily fills space because it's light, whereas sand is heavier to shift and harder to level to be sure that enough is in the measure, especially when workers are tired.

It is very important to measure out the lime and sand quantities into containers that are easy to use and don't create waste (because they are hard to fill and the stuff falls over the edge, etc.), and to make sure that every batch you make is the same as the one before. This is why mixing on a large scale is much better done all at once in a huge mixer – but so far we have not been able to persuade concrete companies to mix lime for us. However, there is now a specialist company that mixes large batches of limecrete, The Limecrete Company, based in Norfolk (see www.limecrete.co.uk).

Preparation

Prepare the place where you want to lay a limecrete floor as you would do for a cement floor: dig it out, lay a stone capillary

break, put up shuttering if necessary, and work out your levels. Then mix the limecrete (see below) and lay it! Keep the mix fairly dry as too much water will make it crack, but level it and float it just like a concrete slab.

Measuring quantities

Work towards using either a whole bag or a half bag of lime as your measure, then this does not have to be tipped out of the bag each time but can be put into the mixer straight from the bag.

Wheelbarrows marked with a marker pen (very important!) work well. Start by working out what volume half a bag of lime fills, mark this on the barrow, then add the other half and mark this as well, so you know what volume both a half and a full bag of lime take up. You'll need three times as much aggregate as lime for the mix, so fill one barrow to the mark you made to show the volume of lime, then offload into another barrow to make sure that both are marked to the same volume.

Another option, once you've marked up the volume that lime takes up, is to fill this volume with sand and then move the sand into buckets, so then you know how many buckets are needed for either a full bag or a half bag of lime.

Once the volumes are worked out, you will need to work out the volume of water needed per mix. Fill a bucket and mark its level, then add this cautiously to the mix (see right), taking care not to add too much. It should be fairly dry at the point where all the sand and lime are mixed together, because after 15 minutes of more mixing it will become much more sticky and workable without adding more water. Once you've got the right consistency – not sloppy but not crumbling apart either – then you will know from the mark on your bucket how much water you've used, and can re-mark your bucket to suit.

Mixing

As the materials are dry, they can be mixed in a cement mixer. A small cement mixer will usually take half a bag of lime to three volumes of sand, but a larger one might take double this. Whatever mixing method you use, all ingredients must be thoroughly mixed together – all lime benefits from long mixing.

- Get all materials ready in the right quantities.
- Start the mixer.
- Add some sand.
- Add some water.
- Add some lime.
- Continue adding, making sure that more sand goes in than lime, and that the mix stays wet until the last lot of lime is added. Remember that it will get stickier as it mixes so be careful not to add too much water!
- Once all the ingredients are fully mixed, continue mixing for 15 minutes before tipping out. This makes the mix much more workable and sticky.

Check the first few mixes for water content and adjust as necessary. Remember that the amount of water needed will be affected by the wetness of the sand – sand underneath the pile will need less water than that on top.

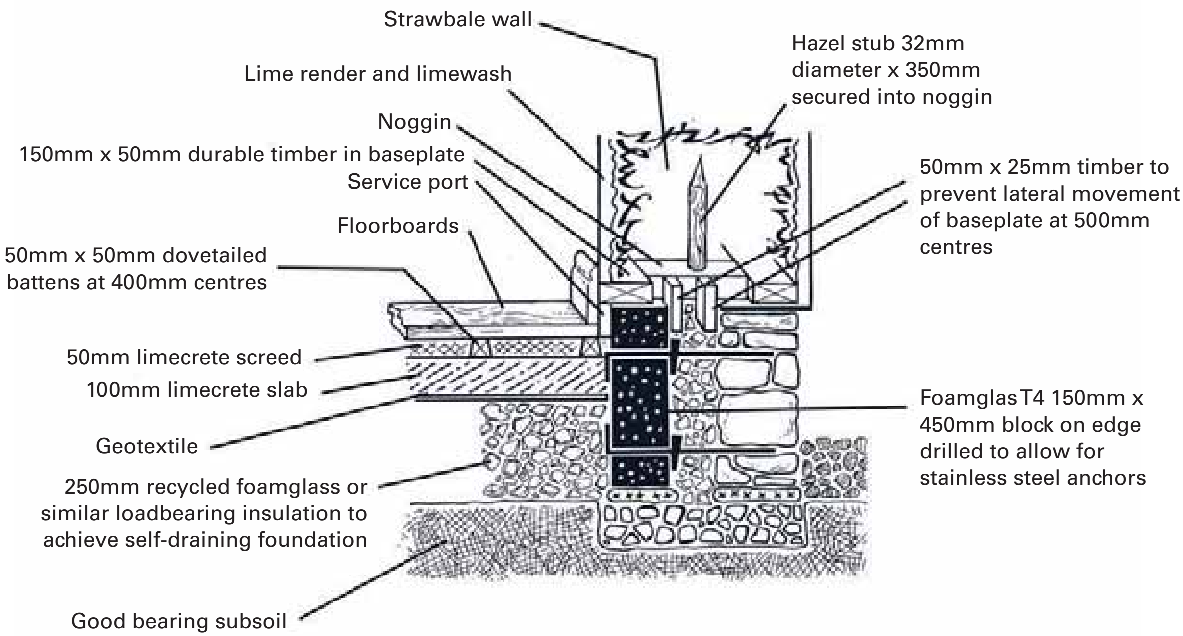
Insulation

It is possible, and recommended, to lay an insulation layer beneath the limecrete (which can be recycled foamglass – see page 60), and to use this insulation material as the aggregate in the limecrete. You will need to take advice to get the quantities correct.

Durability

Limecrete needs to be kept moist but free from drying wind, frost, direct sun and rain. As with any other use of lime, it should be laid in the UK climate only between the end of April and mid-September. It can be walked on with care after two days and built on from this time, but is best left for seven days, and reaches full strength after three months. It is slower to reach full strength than cement, but it becomes as strong as a cement floor in time. Castle, a major cement manufacturer who also manufactures NHL limes, says that its NHL 5 reaches a strength of 5MPa in a 1:2 lime:sand mix after 91 days, which compares with its type N (normal) cement, which reaches 5.2MPa in 28 days.

LIMECRETE FLOOR WITH INSULATION BENEATH



Gypsum plasters and renders

Natural gypsum is just starting to be used again as a render and plaster. It is actually even more sustainable than lime, because it needs to be burned at only 200ºC instead of at 1,200ºC, and it can be recycled very easily. However, it has an undeservedly bad reputation owing to the commercial manufacture of gypsum boards (plasterboard) and the practice of applying a skim finish to them. The glue used to stick the paper on to the board may make it impermeable (although this is not always the case), but the board finish – the skim – does contain glues and additives to make it stick to the paper, and these are also impermeable. It is hoped that natural gypsum, without any additives, will soon become easier to use as a render and plaster.

Cement plasters and renders

There are hundreds of strawbale buildings in the USA and Canada that have been cement rendered. Most of these are doing fine and are not showing any sign of deterioration. Some of them, however, have become very damp as a direct consequence of using a cement render (see Chapter 7).

Cement and lime behave very differently from each other, and are used for different reasons. Whereas lime is a breathable material that holds water within itself while it is raining, and releases it once the rain stops, cement is waterproof and works by preventing water from penetrating through it to the surface beneath. Also, lime is very flexible, whereas cement is not. This means that as long as there are no cracks in the cement, it will stop water from reaching the straw. However, due to its rigidity it is almost impossible for it not to crack after a short period of time, especially when it is applied to a flexible backing material such as straw. This means that when it rains, the rain passes through tiny cracks and filters down the inside face of the cement, and collects at the bottom of the wall, where it cannot get out. A build-up of trapped moisture at the base of the wall over a long period of time causes the rot to set in. This has been identified as a major cause of damp in old buildings, and English Heritage has now banned the use of cement on older lime-rendered buildings.

The other consideration with cement plasters and renders is that because they are not breathable they have the same effect as wrapping the straw in plastic. This lack of breathability creates an unhealthy, unventilated atmosphere around the straw which could lead to damp problems in the long term.

In practice, there may be many instances where you can get away with using cement, or where the life of the building is such that a bit of rot developing at the base of the wall does not matter. **There is no doubt, however, that in terms of best practice, lime renders are superior to cement.**

Chapter 12

PLASTERS AND RENDERS – CLAY

Although these types of plaster are very common in parts of Europe, Scandinavia, the USA, the Middle East and Africa, they are not so well known in the UK and Ireland. Knowledge of their use was almost lost, although we do still have many fine examples of older buildings with a clay mortar binding the bricks or stones together. And of course, our rich heritage of cob buildings, built entirely of clay subsoil, is testament to the durability of clay as a building material. In the last twenty or so years, the use of clay for cob building and plasters has seen a revival of interest as people have come to appreciate its quality and advantages, in much the same way as they have come to appreciate straw, and the two materials work very well in combination.

In recent years European countries have been working in partnership to understand and reclaim the knowledge of working with clay, which is still being used in construction in some parts of Europe, particularly the old Eastern Bloc countries. Whilst the majority of houses in the world are built with clay in some form or another, in Europe we have almost forgotten about this wonderful, tactile, beautiful, natural material. Germany has been the lead partner in two Leonardo projects, the first to write a course in clay plastering and to train teachers, and the second to agree accreditation for this course across Europe. This work, together with that being done by others around the UK and Ireland who are using this great material for building, will help to bring the knowledge of working with clay back to ordinary people and to the construction industry.

So what is clay?

Clay is the finest particle of earth, created by different types of erosion and ultimately made from the weathering of the mountains. When rocks are subjected to wind, rain, ice and heat they will erode, both in a physical sense and through chemical erosion. Big rocks are broken up into smaller pieces, and in descending order of size we know them as rocks, gravel, sand, silt and clay. Clay and silt can often be difficult to distinguish but there is one very big difference between them, which is that clay particles are extremely cohesive whereas silt particles are not.

We tend to be a bit sloppy in our language when talking about clay, and it can be even

more confusing when you read books about earth plasters, using dirt for plastering, etc. The fact is that in many parts of the world there is almost no topsoil, and you can basically dig away at the earth, add straw and water to it and make it into a great plaster or use it to build walls with, hence the terms ‘earth plaster’, ‘earth walls’ or ‘dirt plaster’. This is not the case in the UK and Ireland, however, because even in places where we can take away the topsoil and just use what’s underneath, it’s almost always far too wet and sticky to use without some sort of processing.

It’s always important to take away the topsoil first. This is the growing medium that contains organic matter such as plant roots and worms, and can’t be used to make a plaster. If you dig a hole, underneath the topsoil you should find you come to a layer of undisturbed ground, and this is the subsoil. If it’s clay-rich, then you can certainly use it for construction, both for house building and for renders and plasters, but it will probably need to have water mixed into it first to make it usable, and it may also need sand and fibre adding.

In the UK and Ireland, pretty much any type of clay that you find can be used for plastering, usually with the addition of some sand and fibre. It’s common to find it in river banks in the slow parts of the stream, and in areas that thousands of years ago were estuaries, because, as a very small particle, clay takes a long time to settle out of water, so needs almost still water to do this in.

In the UK and Ireland, pretty much any type of clay that you find can be used for plastering, usually with the addition of some sand and fibre.

As clay is made from local rocks, weathered by rain, as well as being carried by water long distances, it’s quite possible to find a pocket of clay in one area that is completely different from another pocket only half a mile away. Depending on the geology of your local area, you may find a clay subsoil that is ideal for plastering, or pockets of clay that can be added to sand to make a good mix. Clays have different properties because of the rocks they are made from. China became famous for its little yellow clay pipes, made from ‘China clay’, a type of clay that can be fired at high temperatures and makes very fine scientific instruments. This is also the source of the clay in the old-fashioned digestive remedy, kaolin and morphine; it comes from the area in China near Mount Kao-Ling.

We are also familiar in everyday life with another clay, but one that would definitely not be good for plastering – Fuller’s earth, better known as natural cat litter. This is a clay that expands dramatically on contact with liquid – not something we would want our plaster to do! Understanding the nature of clay is a science all of its own, as clays are made up of many different substances. For our purposes, it is enough to say that **all home-made clay plasters should be tested before use** to work out exactly what mix of subsoil, sand and straw should be used.

Testing clays

If you're pretty sure you've got a clay subsoil, you still need to experiment with different mixes to what the optimum mix is for your plaster. Clay subsoil is usually a mix of clay, sand, and aggregate, but you will need to know what proportions they are, and you will need to add fibre (usually straw) to it. To test your subsoil, make up several mixes using exact proportions of subsoil, well-graded sharp sand (sand with angular grains, which includes a good range of sizes) and finely chopped straw, with enough water to make a workable plaster. Usually, you will need the same volume of straw as clay. Vary the amounts of sand and fibre according to the table below, making up the mixes as shown in the boxes marked 'X'. Then make some test panels on a few spare bales, leave them to thoroughly dry, plastering them in panels about 10mm (just under ½") thick and 300mm (12") square, so that you can see the differences between them.

Fibre helps the mix to bind together, giving it tensile strength. Sand makes it strong and durable. Too much clay (glue) without fibre will make the plaster crack and drop off; too much sand will make it crumbly and dusty.

In general, a plaster or render needs about 20-50 per cent clay, but different clays will have very different properties, which is why they need to be tested. Decide which is your optimum mix from your test panels.

Making clay plasters

To be usable, clay or clay subsoil needs to be either very wet or very dry. In the UK and Irish climate it's almost always somewhere in the middle – which means that making your own plasters, renders and cob is going to be hard and time-consuming if you just dig the clay up from your back garden. On the other hand this is tremendously rewarding, and there are some ways you can make it a bit easier. Think about all those lovely villages in Devon, all with their duck ponds – the original source of the material for their houses. In this area, the geology is such that the subsoil is perfect for building when certain other ingredients are added. People would dig what they needed and dump it in the farmyard, then let the cows in to mix it (and add manure), add straw and water, and then build. Overleaf are some ways you can mix your own clay subsoil to make a plaster.

Clay X	1 clay, 1/3 fibre	1 clay, 2/3 fibre	1 clay, 1 fibre
1 clay, 2 sand	X		X
1 clay, 3 sand		X	X
1 clay, 4 sand			X

From wet clay

First find your source of clay, test it as described on page 109, and dig it up either by hand or with a tractor. Dump it on a hard level surface and start mixing it with water and straw. The following are some suggestions for how to do this.

- Make a paddling pool by using a tarpaulin draped inside a circle of bales. Place your clay and sand (according to the mix you already tested) inside this and trample the whole lot by foot in wellies or bare feet, adding water and straw as necessary once the rest has mixed thoroughly. By grabbing the sides of the tarpaulin you can turn the mix over. This is a lot of fun if done in a group, but takes a long time and can be tiring.

- Use a paddle mill. A local potter may have one of these you can borrow. It's a round pan with heavy wheels inside that turn and squash the clay mix; as the pan is turning the clay is scraped off the bottom and sides and dumped back into the mix to be squashed again.

- Use a tractor to drive continuously over the mix, scooping up the stuff and turning it from time to time.

- Use a clay-plaster-making machine. They have really brilliant ones in Germany and other European countries, and we've found a great home-made one in the UK.

- Make your clay thoroughly wet first, like a slurry, then you can mix it with sand and fibre in a big tub using a hand-held plaster mixer.

From dry clay

You can usually get free milled clay from a brickworks, if you collect it yourself. This is dry clay, ground up into small pieces or sometimes powder, that has been processed ready to make bricks or clay pipes. Although it's called clay it often has some sand in it as well, so will always need testing. In this dry form it can be mixed with sand and fibre in a cement mixer, but another way to mix up your plaster is in a large tub using a hand-held plaster mixer (both dry and claggy clay can be done this way). Three-quarters of a tonne of milled clay will cover about 100m^2 when made into a 30mm (1¼")-thick plaster by adding sand and fibre.

From a manufacturer

Womersleys Ltd in Heckmondwike, West Yorkshire (www.womersleys.co.uk) is at the time of writing the only company in the UK making clay plasters commercially. You can buy ready-mixed base coat and finish coat in tubs, and pure clay in lumps to mix yourself for the first (key) coat. The base and finish coats will probably need to be tipped out into a bigger tub and mixed with a hand-held mixer before you use it, as the water in them tends to settle out.

There are also clay plasters available imported from Germany and Italy. They come in dry form in sacks, and you just have to add water. Different grades are available for the base coat and finish coats.

Using clay plasters on straw

Clay is often used for internal walls, but would not generally be used on the outside as a finish except in sheltered positions, or where you have a veranda, because rain would erode it fairly quickly. Prepare your straw walls for plaster first, using a long straw mix where necessary (see page 98), then apply the first coat of clay.

First coat (key coat)

This is a slurry made from pure (or almost pure) clay. Mix up the clay at least 24 hours before you want to use it to make sure it has absorbed all the water it needs to and is really nice and sticky. Dry clay can just be put in a tub with water and mixed using a hand-held plaster mixer; claggy clay should be broken up into small lumps and may need to be soaked for a while before it can be mixed. Often it will need mixing a bit, leaving to soak, then mixing again before it is all a uniform thickness. This clay slurry should have the consistency of thick cream (lovely on your hands!). Apply it by hand (with or without gloves; it's not toxic) direct to the straw, rubbing well in so that all the straw is covered. It's rather like massaging the straw. You're not trying to hide the straw with this coat, only to provide a good key – something for the next coat to hang on to.

Clay plaster won't dry before you've had time to really play with it, move it around, and flatten it out.

Second coat (body, base or backing coat)

This can be applied before the first coat has dried. Or, if it has already dried, wet it down so it is a bit sticky again before adding the second coat, but don't wash it off! This is the coat you made your tests for, so mix up lots of it and call all your friends in, as the work is a lot of fun. The mix should have lots of finely chopped straw in it to give it tensile strength and stop it cracking. You can use a fairly gritty sand, with 4mm (⅙") or even 6mm (¼") maximum-sized grains, as long as it is sharp and well graded. Use this coat to even out any undulations: you can apply it quite thickly, 25-30mm (1-1¼"), and should try to get a flat surface. All this work can be done by hand, but using tools will give a flatter finish. It's best not to use a steel trowel too much as it can draw the clay out of the mix and leave the surface dusty. A wooden or plastic float is best, used to rub the plaster well in. If you're not experienced at plastering and you want a flat surface, now is the time to bring in a professional plasterer, as it does take skill and years of practice to be able to make a flat wall. However, if you're happy with an organic look, then just do the best you can. At least with clay it won't dry before you've had time to really play with it, move it around, and flatten it out.

Finish coat (top coat)

It's not always necessary to apply a final coat. If you're happy with the finish on your body coat you can simply rub it up with a sponge the next day, or smooth it off with a wooden float, or rub it up with a small round stone. There are lots of different finishes and textures you can add to your

plaster, but this is not the place to go into them. It's really beneficial and a lot of fun to go on a course and play and practise with everything that's possible before you make your final decisions about your own plaster. If you do use a final coat, then choose a fine sand to give a smoother finish.

Decoration

You can choose from a range of clay pigments to make coloured plasters that won't need further decoration, but if you do want to paint the plaster then limewashes (see Chapter 11) are perfect, giving a variegated hue and plenty of natural colours. There are also clay paints, and other breathable paints in many colours. It's important to use vapour-permeable paints and finishes to keep the plaster (and straw behind) healthy. To protect outside surfaces from the weather it is necessary to use several coats of limewash, but to protect against driving rain something more is needed. There are many practices from the past and from other countries that have been used, such as adding 1 per cent linseed oil to the final coat of limewash to give it a bit of extra durability. In Arizona they add small amounts of cactus juice to it for the same reason. Once you get hooked on clay you'll discover all sorts of interesting facts about it.

Professional use of clay plasters

Clay is not yet a mainstream plastering material in the UK, but it is growing in popularity. Many professional plasterers are adding clay work to their list of skills and becoming familiar with its properties, and some FE colleges are offering clay plastering as an option. It won't be long now before we have a more widespread take-up of clay and clay products throughout the construction industry, as more people become aware of the need to use sustainable materials, and of exactly what this means.

Clay plasters work brilliantly well, people feel happy working with them because they are truly natural, and they make sense as a material. You can see where you've been; there's no time pressure as they dry quite slowly; you can play around with them, make different textures, shapes and colours; there's no waste as anything that is dropped or dries out can just be remixed with water; and they're not harmful so you can work without protective clothing, as long as you don't mind being spattered with clay!

We use them because they are natural, non-toxic, beautiful, cheap, come from the Earth and go back to the Earth. They regulate humidity in the air (unless you're stuck in an airtight room with a drying source of heat, e.g. radiators!) at pretty much the optimum level for human health. They prevent condensation, deal very well with humid conditions, and help generate that cosy, genial ambience that is associated with strawbale houses.

Chapter 13

PLANNING PERMISSION

Planning policy is a political subject that is determined broadly at national level, and in specifics at local level. While there are general similarities in all areas, there will be differences in policy locally that reflect local circumstances. **However, the fact that a house is built with straw walls is of very little concern to the planners**, although it will be to the Building Regulations department. The planning department, guided by local elected councillors, will have worked out a comprehensive plan for the area that specifies where new housing can be built, which areas are to be kept as green belt, which is agricultural land, etc. Within each area, different types of building will be allowed or not allowed, according to guidelines that have been set by political considerations. It is important to know what the planning policy is for your area, and to understand why the planning authority has made these decisions. For instance, if you wish to build a three-bedroomed house in a local farmer's field in England, you are unlikely to get permission to do so, because the field is probably designated as agricultural land and therefore no domestic buildings will be allowed. However, if you wish to build on a site next to other houses, you probably would get permission.

In Ireland, the situation may be different unless you are near a town, because there is more of a tradition of self-build, and it is much more common for people to build on family land. Also, there are fewer restrictions on securing permission to build because the country is far less populated than the UK.

Most planning decisions are subjective and political, and your planning officer can be of invaluable help in informing you of basic policy, and of particular circumstances in which there may be room for negotiation. It is sensible to recognise your planning officer as someone who has useful knowledge that can be shared with you to enhance your project. An application for planning permission has more chance of success if the planning officer supports it. It is always best to find a way to work together, if at all possible.

Most planning decisions are subjective and political. Your planning officer can be invaluable in informing you of basic policy, and of circumstances in which there may be room for negotiation.

Procedure in Ireland differs from that in the UK. In Ireland, the local council takes the decision, taking objections into account, after which building must not commence for one month. During that month, objections to the council's decision can be lodged, on payment of a fee, with an independent board. The board then makes its final decision based on the council's decision and the arguments of the objectors. Beyond this there is a government appeals system to which you can refer if the decision is unfavourable.

In the UK the local authority makes the decision, based on its policies and any objections raised. If the decision is unfavourable it can be appealed against through a government process.

There are some instances when planning permission will not be required, or will be given automatically once the planning department has been notified. These are called permitted development rights. This may be because what you plan to build is small enough not to require permission, or because it is within your 'curtilage' (garden area), or because you are building an extension – as long as you or previous owners haven't done so before, you are allowed to build up to a certain percentage of the size of your existing house. Listed buildings or those in designated areas may have more restrictive planning policy applied to them in order to preserve our built or environmental heritage.

Areas of concern for planners

What does it look like?

All local authorities will be concerned primarily with this question. In general, your building must fit in with local surroundings: it usually has to look similar to others in the locality and not be an eyesore. Of course, what we each define as eyesore can vary dramatically! Some think concrete bungalows are beautifully modern, and others hate them. In areas of the Pennines, for instance, all houses must be built of local stone. However, some developers have argued successfully that it is acceptable to build out of concrete that looks like stone. And there's at least one strawbale building in that area that has planning permission on the condition that the outside render is stone-coloured. This illustrates really well the possibilities for negotiation that exist within any planning policy.

What will it be used for?

The purpose for the building is important. Are you going to live in it; open it as a shop; store machinery in it; hold band practices? Does it require access for vehicles and a means of dealing with sewage and waste water? Is there a risk of flooding, or vandalism?

What you do in the building has implications for wider services and the impact you'll make on the social and physical environment. Just because you want to live on a greenfield site and make little impact on the

environment doesn't mean the planners will let you. They may be concerned, not about you, but about the owners who come after you when you sell. And just because you think you can deal with your own sewage and waste water doesn't mean that the planners will agree. Besides, some areas will be designated for housing and others for remaining unspoilt. It will be difficult in any area (though not impossible) to cross these boundaries.

What do the neighbours think?

This isn't necessarily as big an issue as it may seem. Planners do have to take into account different viewpoints, and in some areas anything new or different will cause a stir, but there must be legitimate reasons for any objections. Planners may choose not to contend with a powerful local lobby that has no real grounds for objection, or they may think it's politic not to ignore them. However, negative reactions from the neighbours may simply be seen as emotional responses to change, and positive reactions may help you argue your case for innovative design.

Environmental issues & Agenda 21

Every local authority has the duty to implement European directives (Agenda 21) relating to issues of sustainability and protection of the environment. The emphasis these directives are given can vary tremendously from one local authority to the next, but in general there is now greater awareness of the need to build using materials and practices that are less harmful to the planet. If your house fulfils some of these directives, the planners may react more favourably to it, even if it differs in some significant way from other planning guidelines. For instance, a plastered strawbale house may be allowed in an area where most houses are brick because, although it looks different, it provides three times more insulation – thus reducing dependence on fossil fuels, etc – than equivalent houses in the locality.

In the UK

The advice in the box overleaf is given on the UK government website on Planning: www.communities.gov.uk/planningand building/about/planning (accessed July 2009).

Highways Agency

For a development that has relatively small transport implications, you will probably have to submit a Transport Statement (TS) to the Highways Agency; for one that has significant transport implications you will need to submit a Transport Assessment (TA). The TS shows that you have thought about the implications of what you are proposing but there is little that needs to be done, while the TA would show what proposals you would actually be putting into place to deal with any change or increase in transport.

There may also be a need to include a specific assessment of environmental impacts that could arise out of an incremental rise in transport-related noise, reduction in air quality or other pollutions.

Advice from the government website www.communities.gov.uk/planningand building/about/planning.

The planning system controls what can be built and where. Communities and Local Government set national planning policy – ensuring that people have decent affordable homes in well-designed accessible environments while protecting the countryside.

We are currently working to streamline the system, making it simpler, faster and more accessible. We are also getting communities more involved and encouraging more public participation.

Most new buildings, changes to existing buildings or the local environment need planning permission. Planning applications are usually dealt with by your local authority. Local councils also prepare draft plans for their area.

Appeals against refusal of planning permission and inquiries are dealt with by the Planning Inspectorate http://www.planning-inspectorate.gov.uk/.

Many types of building work will require separate permission under Building Regulations.

There is a one-stop source of information on our Planning Portal http://www.planningportal.gov.uk/. It includes advice on planning permission, online applications and guidance on how the system works.

You can also find more information about planning applications and development plans on www.direct.gov.uk/en/index.htm.

You will need to show that you have allowed for enough car parking spaces and bike racks, or that a new access to the highway is safe and visible, or even that you have provided a bus stop if what you are proposing warrants it! You can find out more about all this in the UK from www.dft.gov.uk/pgr/regional/transportassessments.

In Ireland

In Ireland, information can be found on the government website www.environ.ie. You will need a planning permission application pack, available from your local authority, which outlines what you need to do, including putting notices in the local paper and the

numbers of drawings you need to submit. Your application will need to include information about any transport implications.

If you wish to appeal against a planning decision, the independent body that deals with planning appeals in Ireland is An Bord Pleanala. Its mission statement is "To play our part as an independent body in ensuring that physical development and major infrastructure projects in Ireland respect the principles of sustainable development and are planned in an efficient, fair and open manner." See www.pleanala.ie for more information.

One of the earliest strawbale buildings in Ireland, a circular loadbearing house in Co. Monaghan, which was granted planning permission in 1997. *Photograph © Bee Rowan*

Chapter 14

BUILDING REGULATIONS

It would be very unusual for your strawbale house, extension, studio, etc. not to meet current Building Regulation requirements in relation to the strawbale element. We have worked on so many now we have lost count, and have never experienced any problems that couldn't be overcome by discussion! It's important to understand that buildings are 'regulated' in order to make sure that they do not pose a threat to anyone or anything in terms of health and safety, so regulations are very useful when thinking about good practice. They include requirements to make sure that fuel and power is conserved and that people with disabilities can use buildings too. The procedures for dealing with the Building Regulations are different in Ireland and in the UK.

In Ireland the plans, which may or may not include all relevant Building Regulation information, are submitted for approval to the local planning authority, and everything is dealt with by them. The responsibility for ensuring compliance with the Regulations lies with the person who has overall responsibility for the design and its practical implementation, and who oversees the quality of work. It is expected that this will be an architect, but it doesn't have to be. You may have submitted your own plans, for instance, or your building firm may have designated its own person. The local authority may come to inspect your building at any time, but may not.

In the UK, the planning department and the Building Regulations department are separate and require different information, although it is usual for all information to be contained on one set of drawings, submitted to both departments. Ultimate responsibility for ensuring compliance lies with an Approved Inspector, who may work for the local authority but may instead work for one of the independent Approved Inspector companies, set up under new laws a few years ago. These inspectors will insist on visually making sure that certain aspects of the construction are built as agreed: for instance, they will want to see that any low-impact foundation designs that have no cement or plastic in them are built according to plan, or that specified damp-proof courses are actually in place before concrete is poured, and so on. You are required to pay a fee for this service, and it can be very helpful to have the inspector on site if you want to ask any questions.

The Building Regulations for both Ireland and the UK are contained in a number of

documents, called Technical Guidance Documents in Ireland and Approved Documents in the UK. In Ireland they can be obtained from the Government Publications Sale Office in Dublin, and in the UK from NBS Building Regulations (www.thenbs.com/BuildingRegs). There are some differences between them (for instance the Irish Regulations make reference to European Standards as well as British Standards on materials), but one of the most notable (as of July 2007) is that the Irish ones are printed on recycled paper and the UK ones are not!

Both sets of documents are labelled from A to P, including Part L covering the same subjects. They clearly state:

"The adoption of an approach other than that outlined in the guidance is not precluded provided that the relevant requirements of the Regulations are complied with."

Irish Technical Guidance Document

"The detailed provisions contained in the Approved Documents are intended to provide guidance for some of the more common building situations."
and:
"There is no obligation to adopt any particular solution contained in an Approved Document if you prefer to meet the relevant requirement in some other way."

UK Approved Document

'Document A', for instance, refers to the structure of a building and will advise you on the minimum thickness your walls should be and the thickness of concrete you should have in your foundations. This example highlights a major issue around sustainable and strawbale building and the Building Regulations: the Regulations are written to cover the most common types of twentieth-century building materials, that is, concrete, brick and timber. If you are choosing to use other types of materials, or to use the same ones in different ways, then you will have to discuss this with your builder/architect in Ireland and your Approved Inspector in the UK, because there will be no written guidelines. The documents do not mention straw walls 450mm thick, or lime mortar and stone foundations, for instance, or limecrete and leca floor slabs – but this does not mean you cannot use them. On the whole, we would expect the builder/architect and Approved Inspector to be sensible, well-informed people who are up to date with current developments in building practice. These people have lots of useful knowledge that can be helpful to you in designing your building, and can access their colleagues or other advisors if they need to inform themselves further about any subject.

However, there are many people in the construction industry who are not aware that there are other ways of building apart from conventional methods, or who are nervous of stepping away from what they know and what is written in the documents.

This does not mean it cannot be done, and in the UK your Approved Inspector is often the best person to help you with this (together with your strawbale and sustainability consultant, of course!). When contemplating building anything new or unusual, it is necessary to go back to first principles and look at what the aims of the Regulations are. They are there to ensure that whatever is built does not pose a health-and-safety risk in any way and, more recently, that the building is energy-efficient.

All new buildings, extensions and alterations must comply with Part L of current Building Regulations. This covers many aspects of the building, including design to reduce heat loss, provide airtightness and conserve fuel and power. The usual way we do this is by designing for solar thermal efficiency, to utilise the natural energy of the sun to provide heat that can be stored in some materials (thermal mass) and prevented from leaving the building by insulation and good design details. Additional heat could be provided by an energy-efficient heating system, such as an air-source heat pump with under-floor heating.

The Regulations cover all aspects of building, but for our purposes, although the whole building is built predominantly of sustainable, natural materials, the only areas that are substantially different from other building techniques are the walls and foundation design. So the areas of concern for Building Regulations are:

- thermal efficiency (insulation)
- acoustic efficiency (sound insulation)
- fire resistance
- structural performance
- durability (including degradation due to moisture)
- airtightness
- log book, energy ratings etc.

Thermal efficiency

In brick or block walls, this often takes the form of expanded polystyrene or foam (high in embodied energy, and using pollution-intensive production methods) stuck to the back of the blocks inside the cavity of the wall. Other types of eco-construction may use timber and sheepswool or Warmcel as insulation. With strawbale walls, the insulation (straw) can also be the building block – and the surface for plaster – so reducing the need for extra materials. The amount of insulation of a material is measured by its U-value.

The U-value, or thermal transmittance, of a material is the amount of heat transmitted per unit area of the material per unit temperature difference between inside and outside environments.

It is measured in units of Watts per square metre per degree of temperature difference (usually measured in Kelvin): W/m^2K. Put simply, the U-value is a measure of how much heat a material allows to pass through it.

The lower the U-value, the greater the insulation of the material.

Part L of the Regulations (2006) states that the following elements of a new extension or new build must have a U-value no greater than those shown in the table opposite (top).

Element	U-value (W/m²K)
Walls	0.30
Floors	0.22
Flat roof with integral insulation	0.20
Pitched roof with insulation at ceiling level	0.16
Pitched roof with insulation between rafters	0.20
Windows, roof windows and roof lights	1.80
Doors with more than 50% of internal surface area glazed	2.20
Other doors	3.00

Straw bales have a U-value of between 0.13 and 0.20, depending on the quality of the bales used and the degree of skill used in installing them. This doesn't include the render or plaster on either side, which would lower the U-value beyond this.

The high insulation value of straw is achieved because of the width of the bales. Compare the U-values of other common wall building materials, shown in the table below.

Material	U-value (W/m²K)
105mm brickwork, 75mm mineral fibre, 100mm light concrete block, 13mm lightweight plaster	0.33
100mm heavyweight concrete block, 75mm mineral fibre, 100mm heavyweight concrete block, 13mm lightweight plaster	0.40
100mm lightweight concrete block, 75mm mineral fibre, 100mm lightweight concrete block, 13mm lightweight plaster	0.29

Source: Chartered Institute of Building Services Engineers (2002) 'Thermal Properties of Building Structures' in *Guide A: Environmental design*.

There is no doubt that strawbale walls exceed the requirements of Building Regulations for thermal insulation. Further information on the thermal tests conducted so far on straw bales is available in Appendix 1, and on the website of *The Last Straw* magazine, www.thelaststraw.org/resources.

Sound insulation

In The Netherlands research has been done into the sound insulation provided by straw bales (see *The Last Straw* no. 53), and we have overwhelming experiential evidence that straw walls offer far more sound insulation than do walls built with conventional twentieth-century techniques. People who live in, use or visit strawbale buildings remark on the quality of atmosphere found inside them. They are cosy, calm and quiet. They offer a feeling of peace. There are at least two sound studios in the USA built of straw because of its acoustic properties, one in Wales (www.pindropclub.co.uk/strawdio/index.htm), and several more meditation centres. Strawbale walls are increasingly being used in airports and motorway systems as sound barriers to reduce traffic noise. Recently, plastered strawbale walls have achieved Building Regulations approval as thermal and acoustic walls in semi-detached houses.

Fire resistance

There is no question that strawbale walls fulfil all the requirements for fire safety as contained in the Documents.

In 2004 amazonails conducted fire-resistance tests with the Building Research Establishment (BRE), which showed that lime-plastered strawbale walls will withstand fire for a minimum of 2 hours 40 minutes. Compare this with a conventional plasterboard and scrim finish on a timber stud wall, which withstands fire for 30 minutes.

The same tests also showed that it took an hour before there was any temperature difference at all on the side of the wall away from the fire, which is an indication of its insulation value. The fire side of the wall was fired with the same furnace that all building materials are tested with – subjecting the wall to naked flames and temperatures of over 1,000°C.

Unfortunately there was not enough money available to extend these tests up to British Standard (the only difference being that the wall system would have to be larger, at $3m^2$, rather than the $1.5m^2$ walls tested), but the results are the same as have been demonstrated in many other countries: see www.thelaststraw.org/resources.

It is a popular misconception that strawbale buildings are a fire risk. This misconception seems to come partly from the confusion of straw with hay, and the collective memory of (relatively rare) spontaneous combustion in hay barns (from large haystacks baled too wet and green). Straw is a very different material from hay, and there are no known cases of spontaneous combustion with straw, even when stored in poor conditions.

There is a risk of fire with straw, however, during the storage and construction process. It is loose straw that is the risk, since it combusts readily. If you were to cut the

strings on a bale and make a loose pile of the straw, it would burn very easily as it contains lots of air. Therefore it is essential to clear loose straw from the site daily, store straw bales safely, have a no-smoking policy on site, and protect the site from vandalism. If a wall is to be unplastered for a while, be sure to trim it, getting rid of the 'fluffy bits' that would encourage the spread of flames.

Once the straw is built up into a single bale wall it tends to behave as though it were solid timber, particularly when it is load-bearing and therefore under compression, but also when used as infill. In a fire, it chars on the outside and then the charring itself protects the straw from further burning. It's like trying to burn a telephone directory – if you tear loose pages from it, they will burn easily, but if you try to set fire to the whole book, it's very difficult.

When the wall is plastered both sides, the risk of fire is reduced even further, as the plaster itself provides fire protection.

For the purposes of Building Regulations, a wall built of any material that is covered with half an inch of plaster has a half-hour fire protection rating, which is the requirement for domestic buildings. All the fire-testing research done on strawbale walls concludes that this type of wall-building system is not a fire risk. A list of research documents can be found in Appendix 3 and on *The Last Straw* website.

Research in the USA and Canada reached the following conclusions.

"The straw bales/mortar structure wall has proven to be exceptionally resistant to fire. The straw bales hold enough air to provide good insulation value but because they are compacted firmly they don't hold enough air to permit combustion."

Report to the Canada Mortgage and Housing Corporation by Bob Platts, 1997

"ASTM tests for fire-resistance have been completed. The results of these tests have proven that a straw bale infill wall assembly is a far greater fire resistive assembly than a wood frame wall assembly using the same finishes."

Report to the Construction Industries Division by Manuel A. Fernandez, State Architect and head of Permitting and Plan Approval, CID, State of New Mexico, USA, 1997

Structural performance

The requirements laid down in 'Document A: Structure' are for brick, concrete or timber walls. You will find no guidance here for building strawbale walls. This does not mean it cannot be done! Research in the USA has shown that structural loadbearing strawbale walls can withstand loads of more than 10,000 lbs/sq ft, equivalent to 48,826 kg/m^2.*

There is no doubt that loadbearing straw walls can withstand greater loads than will be imposed on them by floors, roofs and possible snow loading. It is the design of associated timber work, the even spread of loads around the walls, and the quality of building that is crucial here, not whether the straw can do it.

With infill walls, in timber-frame structures, the straw does not take weight anyway

* Ghailene Bou-Ali (1993) *Results of a Structural Straw Bale Testing Program.* MSc thesis published as a summary by the Community Information Resource Centre, Tucson, Arizona.

and there are conventional calculations available for the structural strength of other types of framing.

Durability

This is the area of most concern when designing strawbale houses in order to comply with Building Regulations.

Will the strawbale walls retain their structural integrity over time, or will they suffer material degradation caused by moisture, from either condensation, rain or ground water? While this is a consideration for all house builders, in fact all that Building Regulations require is that the walls pose no threat to health and safety. There has been no research to date on the durability of strawbale houses in the weather conditions we experience in the UK and Ireland, but we are conducting research, in partnership with Lincoln University, on loadbearing strawbale council houses built for North Kesteven Council. What little research has been done in the USA and Canada shows that there should be no need to be concerned that strawbale walls will not withstand the test of time and the rigours of our climate. The key to durability lies in good design, good-quality work and maintenance. Past experience is an allowable and viable method of establishing the fitness of a material, as it says in the Documents, provided:

"The material can be shown by experience, such as its use in a substantially similar way in an existing building, to be capable of enabling the building to satisfy the relevant functional requirements of the Building Regulations."

Irish Technical Guidance Document

"The material can be shown by experience, such as in a building in use, to be capable of performing the function for which it is intended."

UK Approved Document

There is also a specific reference to the use of short-lived materials in the UK Documents:

"A short-lived material which is readily accessible for inspection, maintenance and replacement may meet the requirements of the Regulations provided that the consequences of failure are not likely to be serious to the health or safety of persons in and around the building."

Not that straw is a short-lived material, but this clause should reassure anyone who is still not fully convinced of the capabilities of straw. In any case, a building that is designed well and built well should not experience any long-term effects of degradation due to moisture. There are plenty of examples in the USA of strawbale houses enduring for over 50 years with no signs of deterioration. The oldest known ones still inhabited today were built in 1903 in Nebraska, and the oldest in Europe is near Paris, built in 1921. In the UK and Ireland we have only fifteen years' experience of building with straw bales, so it cannot yet be said that strawbale buildings will survive for long time periods in our climate. We do, however, know that even if there is degradation of the straw it is easily repaired, and that it degrades slowly and therefore poses no risk to safety.

Airtightness

The airtightness test is used to determine a building's air leakage, and basically determines whether your building has been designed well, and then built well. Obviously, heat will escape from anywhere that air does. For the test you have to close all the windows and doors and use a machine that sucks air out of the building. The rate at which air moves, and is therefore being sucked into the building through unintended gaps, is then measured. Most problems in standard designs occur at the junction between the roof and walls, around windows and doors, and around electrical boxes. Buildings larger than $15m^3$ need to be tested and their air leakage proven to be no worse than $10m^3/hr/m^2$ at 50Pa. As far as we are aware, only one UK strawbale building has been tested to date, and the tester said it was the most airtight building he had ever tested, at $1.56m^3/hr/m^2$! We are not at all surprised, and would expect the same results from all our strawbale buildings. We have some very good design details for straw that are now being used in mainstream construction.

Most problems with airtightness occur because of poor-quality work and lack of understanding of the reasons for following designs accurately, coupled with using out-dated designs that can't really be improved, such as the cavity wall system. It's common for electricians installing electrical back boxes to break through the internal concrete block skin into the cavity of the exterior wall, thus exposing the building to air leakage via the cavity. Monolithic wall systems such as strawbale ones can never suffer from this defect and are therefore inherently better, reducing the potential for poor-quality work. Not only that, but strawbale builders are usually very conscientious people who have chosen this type of construction for very sensible reasons, and when we run courses to help them build, we use a process that involves each person in a thoughtful and responsible way. Building with this sort of awareness can create much better-quality buildings. We pay attention to the process of building as well as the function, and it produces amazing results!

Log book and energy ratings

New buildings are now required to have a log book. This details lots of information about the building, including the type of construction. It also shows the calculations based on type of insulation, floor-to-window area ratios, U-values of different components, etc., which combine to produce a figure showing how energy-efficient the building is – the SAP (Standard Assessment Procedure) rating (or similar). The log book for a straw-bale building would also include details of how to maintain the walls and plaster/render, what to do in case of accident, e.g. water penetrating the bales due to storm damage on the roof, etc., how to fix things to the walls, and how to make extensions or alterations.

And finally . . .

Lastly, a word of caution about Building Codes, Building Regulations and building practice in general.

You need to be careful about what you read in books and on the internet about

strawbale building and how it must be done. Much of the information available is based on US Building Codes and methods of building, which are not necessarily appropriate for Ireland and the UK. There is an increasing body of knowledge available about practice in Europe, but we would not necessarily agree with all of it. We would encourage you to inform yourself as fully as possible of the principles of good strawbale design, and then make up your own mind.

There is a fundamental difference between Codes of Practice in the USA and some other European countries, and our Building Regulations. Other codes may be prescriptive: that is, they tell you that you MUST do it a certain way. In Ireland and the UK, Building Regulations are guidelines. They advise you on best practice, but you can do it another way if you can show it's effective.

Prescriptive codes can mean that as new and simpler techniques are developed and the nature of straw is understood more fully, new practices cannot be used officially until the Building Codes have been altered. For instance, the Codes in some US States require that stucco wire must be used on straw buildings that are cement-rendered. This means that even if you are sure it is not necessary you still have to do it. Very quickly it becomes 'fact' that strawbale buildings must be wrapped in stucco wire, when the reason for the 'must' has become lost. In Germany it is still not permitted to build loadbearing strawbale buildings, even though we have been doing it here with full legal approval for fifteen years! So it is healthy to practise common sense, coupled with an enquiring mind.

When faced with a choice about whether or not to try a new or different construction technique, always ask yourself first: Does it work? But don't stop there. Ask the most important question next: Is it necessary, or does it just over-complicate the building? And finally, ask yourself: Do I have the knowledge, skills and support required to carry out my dreams? The best strawbale homes are straightforward, beautifully simple (often simply beautiful!), and created as the result of many people's efforts.

Appendix 1

HUMIDITY IN STRAWBALE WALLS

by Jakub Wihan

The doubts that generally come to mind in connection with strawbale walls are always related to fire, rodents and moisture. While worries about fire and animals can easily be dispelled by the application of good plaster on to the straw, the question of the vulnerability of straw to humidity is potentially more serious and is worth looking into in detail.

Even in the often-wet climate of the UK and Ireland, straw will become damp only in certain situations. When a farmer finds some old bale in a forgotten corner, it is likely to still be in very good shape after many years or even decades unless it sits on damp ground, is covered so that fresh air can't get to it, or is exposed to leaks, condensation or direct rain. So, according to the experience of any farmer, a wall of stacked bales that is built on a tall and draining plinth and covered by a generous overhang will last for a very long time, even in a very humid climate such as that of the UK and Ireland.

Questions start to spring to mind when contemplating building a strawbale house on a site exposed to severe winds. For example: **Will the render shield the straw enough from driving rain?** And if the rendered straw gets wet for some reason, **doesn't the render then prevent the straw from drying?** And, most importantly, **doesn't the cold weather cause condensation within a strawbale wall?**

Research: where are problems most likely to occur?

Houses built out of straw and hay bales more than 100 years ago in the Nebraskan desert are failing to give us convincing answers to the above questions, because there is not much that can go wrong with a strawbale house in a desert climate. But since people in the late 1980s started building in a more humid environment, in the UK and Europe, the effect of moisture on strawbale walls has been the subject of numerous investigations. This has given an idea of:

- how different plasters and renders influence humidity levels within the straw
- the relationship between humidity and potential straw decomposition
- the most common causes of straw rot in walls.

A questionnaire* sent to professional strawbale builders all around the world in June 2004 was used to create a database of 174 moisture problems in strawbale walls that those builders had repaired during their careers. Almost a quarter of all the cases of serious moisture damage related to bad window or door detailing, where leaking windowsills were the most frequent causes. One in six reported moisture problems was related to a leaky roof, and only slightly more – 30 cases out of the 174 – had rotting straw in their walls due to wind-driven rain. The window detailing can't ever be under-estimated in strawbale building, because the window and door surfaces tend to collect large amounts of concentrated water during rain. This water is then usually driven by wind into the bottom corner of the recessed opening, where it is likely to find its way into the wall through any cracks between the render and the frame. Figure 1 shows window detailing designed for extra protection against water ingress.

The roof above strawbale walls needs to be finished with the utmost care, and the same applies to all external straw protection. The

Figure 1. Extra corner protections embedded in window frames and generous (sometimes doubled) windowsills with drip edges will guarantee the owners of any strawbale building sound sleep at night. Picture: Carol Atkinson's strawbale cabin in Howden, East Yorkshire.
Photograph © Jakub Wihan

* Detailed analysis of this questionnaire is included in: Wihan, J. (2007) *Humidity in Straw Bale Walls and its Effect on the Decomposition of Straw*, MSc Architecture thesis written for the University of East London. Available at www.jakubwihan.com/pdf/thesis.pdf.

render quality, for example, can't be compromised. For this reason, it is best practice to use traditional lime render (using well-graded sharp sand and mature lime putty in the ratio 3:1 – see Chapter 11), applied when there is no risk of frost and to the best possible standard.

What we know about straw is that it gets wet quickly – but it also gets dry quickly! One case study that demonstrates serious moisture damage caused by the application of lime render too late in the year comes from the southern ocean front of Brittany, France. A pair of strawbale semi-detached houses had been built in a village only about 100 metres away from the cliff edge, where severe, long-lasting storms make local stone dwellings extremely wet during the winter. Insufficiently carbonated, vulnerable and soft lime plaster didn't manage to protect the straw from heavy winter rain that had been driven by very strong coastal winds into the exposed wall constantly for two days. As a result, straw in the wall on one house got wet all the way through, so that wet patches appeared on the interior plaster of the building. Almost immediately after the incident the house started to smell of rot.

The owner of the house took a risk and, rather than trying to dry the walls, he decided to clad the entire house in timber to prevent any further damage. Wet straw, protected by cladding, although covered in soaked plaster, dried out to a satisfactory level in about four months. Decomposition stopped and, since the disastrous storm, the house has been used for its original purpose without any trace of bad smell or straw rot. **This shows us that even saturated straw can dry out fairly quickly in the right conditions, resulting in no long-term problems.** Timber-clad strawbale walls on this house are performing in this extreme climate, where outdoor humidity levels rarely drop under 75 per cent relative humidity (see box below), remarkably well.

According to the experience of building with straw in similar conditions in the UK and Ireland, properly made and executed traditional lime render, if carbonated enough (the finishing layer applied in mid-September at the latest), has proved able to protect straw from driving rain in most situations. However, in areas of extreme exposure (on gable walls, for example), it is recommended that the plastered strawbale walls are clad in timber, or at least that some trees are planted in the direction of prevailing winds to protect the walls.

Relative humidity

The amount of water vapour in the air at any given time is usually less than that required to saturate the air. The relative humidity is the percentage of saturation humidity, generally calculated in relation to saturated vapour density.

$$\text{Relative humidity (RH)} = \frac{\text{Actual vapour density}}{\text{Saturation vapour density}} \times 100$$

Moisture monitoring

In order to bring peace of mind to strawbale home owners, it is also recommended that they monitor humidity levels in any potentially questionable section of their strawbale walls. Generally, the area of interest is the bottom of the most exposed wall, as the moisture tends to gather at the baseplate. Good monitoring points are towards the bottom of the bottom bale, just above the baseplate, aligned with the sides of the windows. The data indicating the greatest values of relative humidity or moisture content generally come from the exterior side of the wall (see box below). The exterior monitor is usually buried in the straw, about an inch away from the inner surface of the exterior plaster. The central monitor, placed halfway through the wall, will collect other useful data. This way it is possible to check the depth of any moisture intrusion and thus assess the seriousness of a problem. The central and exterior monitors should never share the same hole in the wall, but they should be as close to each other as possible. It is reassuring for homeowners to know the pattern of moisture activity within

The humidity profile in a wall

The relative humidity (RH) profile through a wall changes gradually from the exterior humidity level to the interior humidity level over the thickness of the wall. The closer to the exterior we monitor inside the wall, the closer we get to the exterior values of RH. The gradient of the curve characterising the change of RH across the wall – its steepness – depends on the difference between the exterior and interior RH and on the property, individual to each different material, called the water vapour diffusion coefficient (WVDC). If the render is closed – not breathable (or vapour-permeable) – it has a high value for its WVDC and the curve over the thickness of the render tends to be steep. That is why we usually find quite different RH levels just behind the render compared with the exterior environment, although this difference gets smaller the more breathable a plaster we use.

Clay plaster generally has the lowest WVDC of all renders and plasters, followed by traditional lime render. Cement has the highest WVDC value, which might suggest that the cement render is the best in protecting the straw from any very humid environment. **However, the opposite is in fact true. Cement render, *because* of its high WVDC, prevents straw from drying out.** It has been proven by many years of experience in the USA, where cement renders had been used on strawbale buildings initially, that it fails to protect the straw from high humidity levels outside the wall despite a high WVDC, because of the shrinkage cracking of cement. Shrinkage cracking happens inevitably during the drying process of cement mortar. Shrinkage cracks are invisible capillaries leading the moisture deep into the cement, making it wet all the way through, and having a disastrous effect on straw, which is then left wet and unable to dry.

a strawbale wall over the year; this way they can be sure that their straw protection is doing the job it's supposed to do.

There are several options when choosing appropriate monitoring equipment. Depending on your budget and aim of your research, you can build a moisture probe of your own or buy a factory-manufactured data logger. These tools measure either moisture content or relative humidity – see page 133 for more about how these relate to each other.

Make your own moisture probe

Canadian and UK research shows that home-made wood-disc moisture probes (see Figure 2), if built properly, are capable of giving the owner of a strawbale building fairly accurate readings of moisture content in a strawbale wall. They are cheap and easy to make. They require a discipline in regular data collection and any kind of cheap wood moisture meter to view the readings. One handheld wood moisture meter will serve all the probes installed.

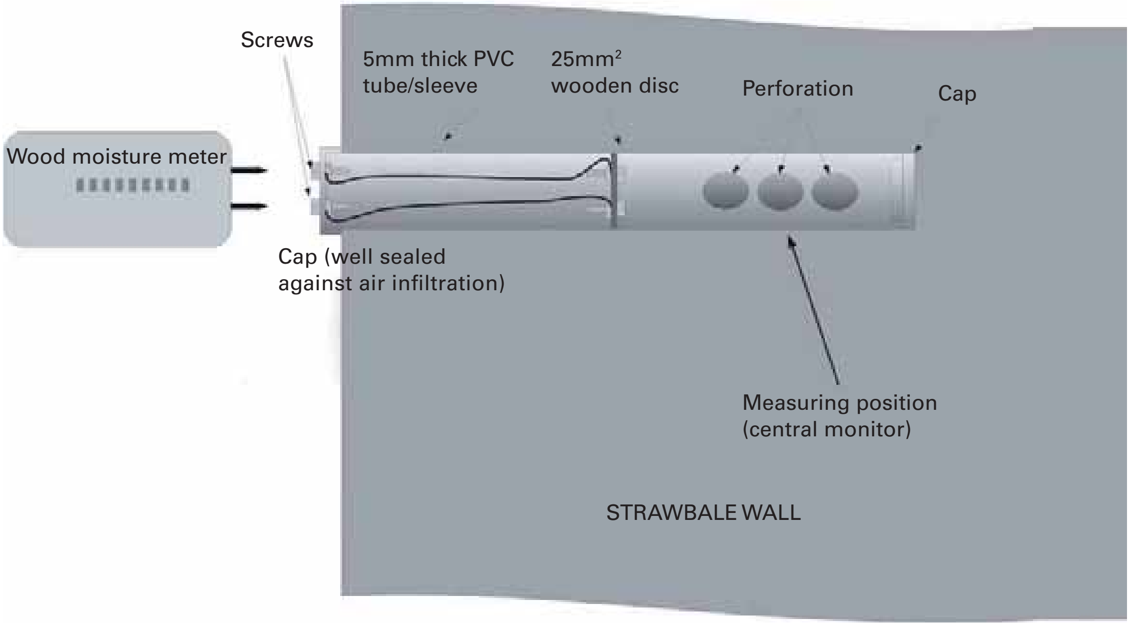


Figure 2. The wood-disc moisture probe is like the moisture meter's extended arm. It allows the moisture meter to extend its sensors towards the desired monitoring position within the wall (in this case towards its centre), where it measures the moisture content in a 5mm thick, 25mm wooden disc that always has the same moisture content as the surrounding straw in that particular location. The couple of screws and the cap sticking out of the wall need to be perfectly sealed against air infiltration, as do any cracks in the plaster around the protruding cap. *Image by participants of the Humidity in Strawbale Wall course run by amazonails in France.*

Or buy a data logger

While wood-disc moisture probes are capable of showing directly the moisture content of straw in a measured location, data loggers (see Figure 3) are generally calibrated to measure relative humidity in the air surrounding the straw. The advantage of a data logger is in automatic data collection – a data logger can be set up to store in its memory thousands of readings. The data are automatically collected at regular time intervals (from one minute up to an hour). However, the data logger doesn't give an immediate picture of measured data, unless it is pulled out of the wall and plugged into a computer. Once displayed on a computer screen, readings show the development of humidity levels in a strawbale wall over time, in a colourful chart with satisfactory precision.

Home-made wood-disc moisture probes are the most convenient option, as they give the homeowner instantaneous readings and thus an early warning of any moisture problem. Data loggers, on the other hand, serve the best in providing consistent, reliable readings for more in-depth research into humidity development within strawbale walls.

Before deciding on the best monitoring approach for you, it is useful to have a clear understanding of the difference between *moisture content* and *relative humidity*.

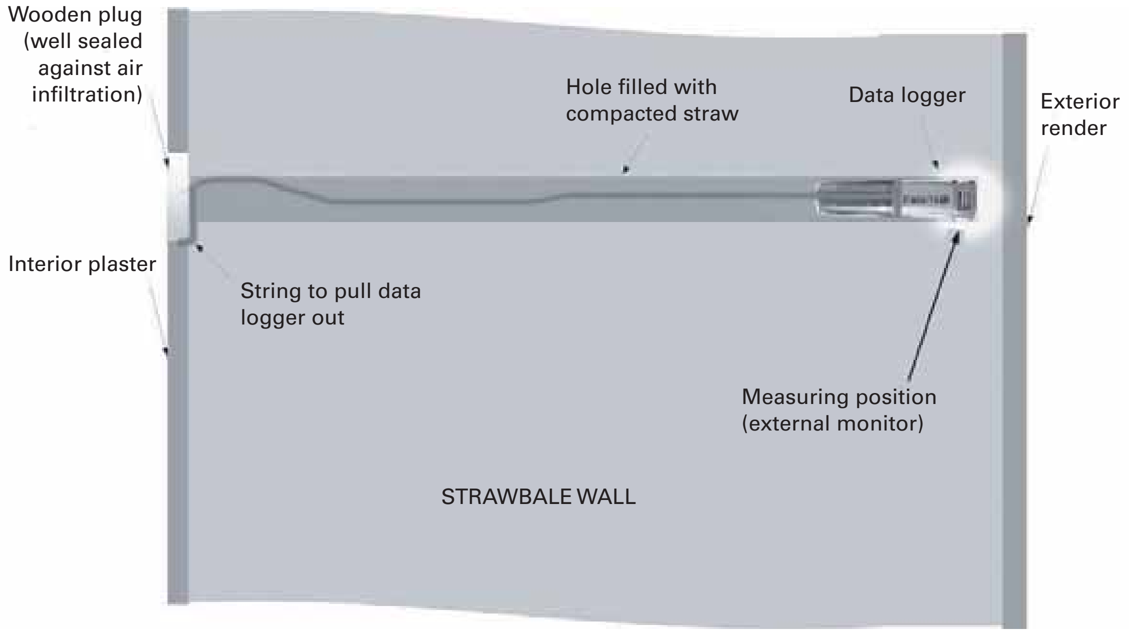


Figure 3. A section through a strawbale wall with a data logger in the external monitor position.

Moisture content and relative humidity

Hygroscopic materials

Some materials, such as glass, are indifferent to changes of humidity that surround them. If we weigh a piece of glass that has been in an environment with very dry air (in a desert, for example), and then compare its weight after it has been rained on for a while, this will hardly change. Materials such as glass or steel are called 'non-hygroscopic', which means they are indifferent to moisture.

Most building materials, however, are hygroscopic, which means that their weight gradually increases if, for example, they are suddenly transferred from the Sahara to West Wales. The extra weight relates to the quantity of liquid water adsorbed (see box below) from the air into the porous structure of the hygroscopic material. Straw, wood, concrete, most renders and plasters are hygroscopic and porous, and the amount of adsorbed water – the *moisture content* – is closely related to the humidity of the air that surrounds them, the *relative humidity.* The more humid the air, the more the hygroscopic material will adsorb liquid water.

Relative humidity and moisture content in different materials

The exact amount of moisture adsorbed by a material depends on the material's microscopic structure, particularly on the number of pores and their sizes. At the same level of atmospheric humidity, materials such as straw and wood will tend to adsorb more moisture than brick, for example, because straw and wood are more sponge-like in the

Adsorption by hygroscopic materials

Hygroscopic material surrounded by water vapour in the air attracts water molecules to its surface by tiny electromagnetic forces. The surface is often very rough, with – from the water molecule's perspective – lots of caves and canyons. The tinier the crack, the more attraction, thus water molecules are trapped in very small capillaries, where they tend to stick together to form miniature liquid drops in a process called *adsorption.* That is why the material gets wet when surrounded with humid air and that is why the weight of a hygrosopic material changes in these conditions – it is influenced by the presence of liquid water within it.

Adsorption is a different process from *absorption.* A*d*sorption is the accumulation of atoms or molecules on the surface of a substance. A*b*sorption is where atoms or molecules actually penetrate into another substance.

sense of having much more microscopic pores.

The relationship between relative humidity and moisture content is unique for each material, and can be determined by a simple test. A sample of a material is placed in a room with stable relative humidity for a couple of days. This will allow enough time for the sample's weight to settle. Once the weight is stable, the material's moisture content is in equilibrium with the room's relative humidity, and the sample can be thoroughly dried in an oven. The completely dried sample is weighed at intervals until the weight stabilises, and the difference between the weight of the sample before and after drying will reveal the exact mass of moisture adsorbed by the material in the room with that particular relative humidity. Moisture content can be calculated on a wet-weight basis or a dry-weight basis.

Example 1
A 1.11kg bunch of straw that has been in an environment with 50% relative humidity for a couple of days weighs 1kg after thorough drying in the oven. This means that the sample had adsorbed 0.11kg of water at 50% relative humidity.

The percentage of dry-basis moisture content refers to the weight of water divided by the weight of dry material.
Dry-basis straw moisture content @ 50% relative humidity = 0.11/1 = 11%.

The percentage of wet-basis moisture content refers to the weight of water divided by the weight of wet material.
Wet-basis straw moisture content @ 50% relative humidity = 0.11/1.11 = 10%.

Example 2
The same sample of straw has been placed for a couple of days in an environment with 80% relative humidity. It gained 0.2kg of water, hence:

Dry-basis straw moisture content @ 80% relative humidity = 0.2/1 = 20%.

Wet-basis straw moisture content @ 80% relative humidity = 0.2/1.2 = 17%.

Researchers carrying out tests on the same sample of straw repeatedly, each time in an environment with different relative humidities, plot the results of their investigation as a curve, known as a sorption curve or sorption isotherm (see Figure 4).

Straw decomposition

An important investigation* on samples of straw has shown that there is a certain borderline at which straw starts to significantly decompose. And, as UK and Irish farmers might expect, this borderline relates to an environment with very high relative humidity. Even in very humid air, with relative humidity up to 95 per cent, straw decomposes at an unnoticeable rate, but once relative humidity gets higher than about 98 per cent, straw starts to rot.

What does an environment with 98 per cent relative humidity look like? Air with 100 per cent relative humidity is saturated with water vapour, which starts to show on all material surfaces as liquid water. 100 per cent relative humidity in nature refers to dew, fog or rain. It is not surprising that

* Summers, M. D., Blunk S. L. and Jenkins, B. M. (2003) *How Straw Decomposes*, EBNet Straw Bale Test Program, DRAFT 12/8/2003. Available from EBNet database: www.ecobuildnetwork.org/pdfs/How_Straw_Decomposes.pdf.

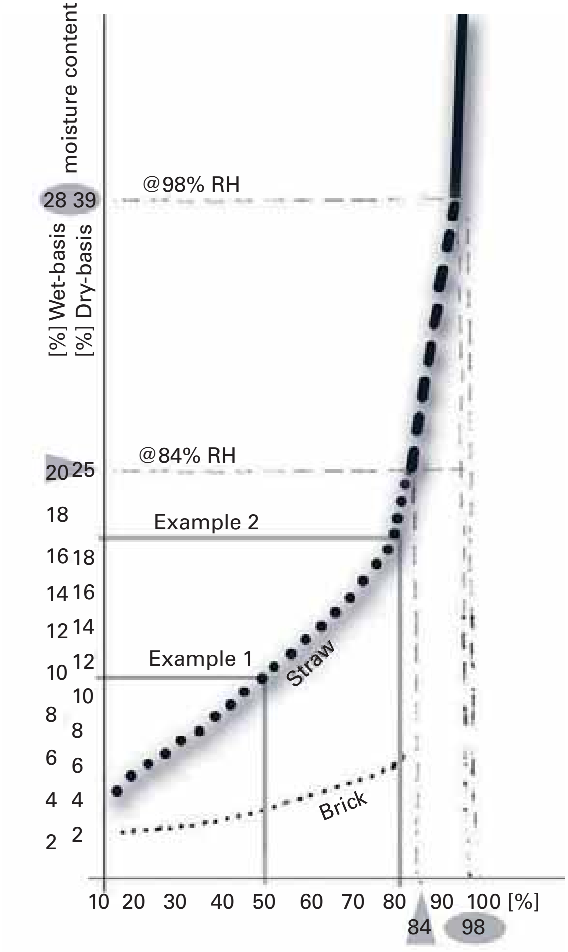


Figure 4. The sorption curve, or sorption isotherm, is different for each material and can be usually found among basic building material characteristics, provided by the manufacturer. Sorption isotherms of different straw samples are well known as a result of agricultural research. The thick dotted curve shows levels of safe moisture content and relative humidity. The dashed portion of curve shows the danger zone, with potential moisture problems, and the continuous thick black line refers to levels of relative humidity and moisture content that cause significant decomposition of the straw.

straw at 100 per cent relative humidity – at this point practically covered all over with liquid water – starts to rot. What is reassuring, however, is that according to the research it doesn't significantly decompose until almost at that very point.

The same investigation has shown that very slow straw decomposition, although unnoticeable, can be recorded by very sensitive laboratory equipment in an environment with 84 per cent relative humidity. Strawbale builders have taken this value as a limit for a healthy condition within a strawbale wall. **It has been generally agreed that data loggers showing relative humidity readings above 84 per cent in a strawbale wall are usually referring to a potential moisture hazard.**

Measurements of relative humidity have one great advantage. A data logger measuring relative humidity in the air shows clearly how close the environment is to creating a moisture problem. This level is 98 per cent relative humidity, or, to be on the safe side, a benchmark of 84 per cent relative humidity.

In order to assess the danger of a potential moisture problem with measuring equipment showing moisture content values, rather than relative humidity values (using a home-made moisture probe, for example) one needs to have the relevant sorption isotherm handy. The straw sorption isotherm shows that a hand-held wood moisture meter referring to a dry-basis moisture content above 25 per cent, or a wet-basis moisture content above 20 per cent, shows readings in the danger zone, because it can be seen from the sorption isotherm that the level of relative humidity in the air surrounding straw with this moisture content is above 84 per cent. The sorption isotherm also reveals that significant decomposition starts when straw has adsorbed as much moisture as is equivalent to 39 per cent dry-basis moisture content, or 28 per cent wet-basis moisture content, which relates to 98 per cent relative humidity.

Note: The building industry prefers to use the *dry-basis moisture content*, which is what the handheld moisture meter would probably be showing. However, most of the moisture meters used by the food industry and agriculture will give *wet-basis moisture content* readings, although this isn't a rule. Before using any moisture meter data it is crucial to find out which moisture content the meter had been calibrated for.

When moisture conditions change quickly

Although the difference in meaning between moisture content and relative humidity is that the former relates to the weight of water contained within the material structure and the latter refers to the saturation level of water vapour in the air, the most important difference for practical purposes, i.e. when monitoring moisture, is in the speed of reaction of the material to changing conditions.

A data logger measuring relative humidity will respond to sudden changes in humidity levels within the environment quickly with great accuracy, while it can take hours or sometimes even days for straw to settle to its final weight with a relative humidity change. In fact, the perfect balance between relative humidity and moisture content can never be fully established, because the percentages of relative humidity in a wall change all the time on a daily basis. In reality, monitors of straw moisture content just can't react so quickly. Moisture content might almost seem like relative humidity's slower sibling. Observations show that in an environment with changing humidity levels, the straw moisture content always tends to rather lazily correspond to lower levels of relative humidity, while ignoring its peaks (see Figure 5).

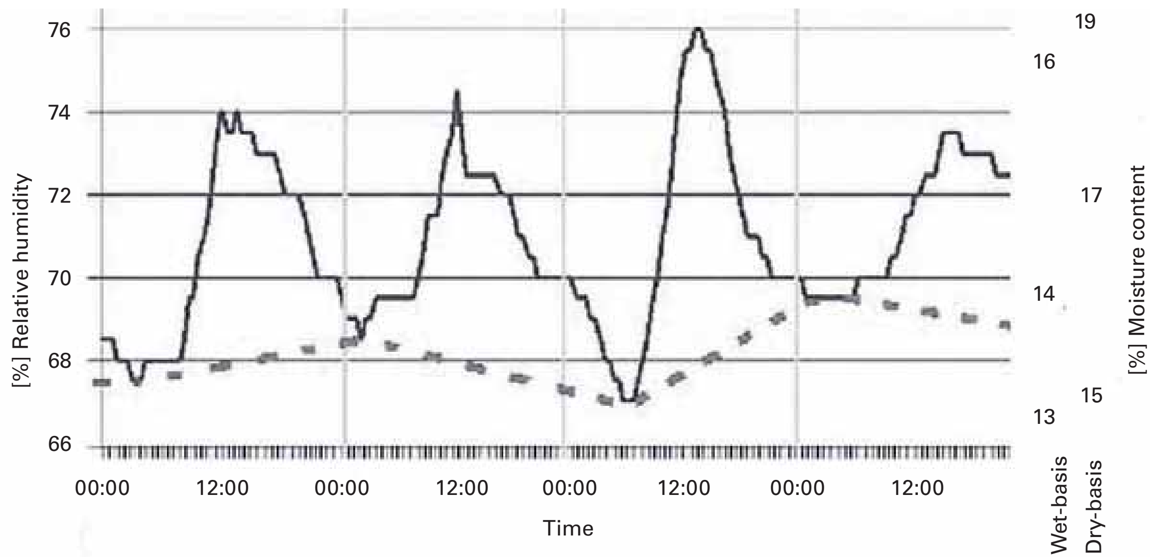


Figure 5. Data logger readings (solid line) in an external position (in straw, a few inches away from the outdoor environment) reflect the pronounced daily fluctuations of outdoor relative humidity. At the same time, measured straw moisture content in the same location (dotted line) keeps relatively stable, corresponding to lower values of relative humidity.

This fact needs to be fully understood when measuring relative humidity by data logger. Even though the data will peak daily at a certain level, it is actually the troughs that are giving us a picture of the true amount of moisture adsorbed by straw in given fluctuating conditions.

What we know about humidity in straw

- Mould growth and rot occur only when relative humidity levels are at 98 per cent or above (where 100 per cent = rain, fog or dew).
- Even when relative humidity around straw reaches this level, it has to remain there for a considerable time (two days) for it to affect the straw bale, because straw adsorbs moisture quite slowly from the air. This level of moisture in the air remains at 98 per cent for as long as two days only in a rainforest.
- Strawbale builders generally take a level of up to 84 per cent relative humidity to be a safe threshold.
- A dry-basis moisture content of 25 per cent, or a wet-basis moisture content of 20 per cent, is equivalent to a relative humidity reading of 84 per cent.

- Straw will adsorb moisture quickly if it is in direct contact with water, for example if it sits in a puddle, if wind drives rain through unprotected straw, or there is a hole in the building's roof.
- Straw will dry quickly once the source of water has been removed and good ventilation is applied.
- Even if mould growth has occurred, it will stop and the straw will become healthy again once the straw has dried out.

Guidelines for healthy straw houses

To keep straw houses healthy and free from mould growth or rot they need to have:

- good ventilation – all plasters, renders and surface finishes should be vapour-permeable, and there should be at least 500mm (20") of clear space around each exterior wall
- protection from the damp of the earth and rain splashback – straw should be raised up at least 300mm (12") and preferably 450mm (18") from the ground on self-draining non-porous foundations
- protection from leaks – a good overhang of at least 450mm (18") on the roof and all maintenance carried out when necessary
- protection from driving rain – fully carbonated lime render, timber cladding and rain screens in areas of extreme exposure
- protection from condensation – use of vapour-permeable plasters and finishes with good ventilation.

There are some circumstances in which it is good common sense to adapt the best practice guidelines above to suit particular conditions. For example, it is sensible to tile bathrooms and kitchens to protect plastered straw walls from direct water contact. Similarly, timber cladding may be required in areas of extreme exposure outside. However, all these areas will benefit from having as much vapour-permeable material around them as possible, as straw needs good ventilation to remain healthy, so keep tiling to a minimum and use clay or lime plasters in the rest of the room.

If you want to have a truth window with a glass front, or to show off your straw walls through a perspex cover, as long as you have enough ventilation around nearby this should not present a problem.

Intuition

None of the studies conducted to date has made any groundbreaking discovery. The results support the common knowledge of natural materials that had been, until recently, carried through generations by handing down experience. Straw, like wood or other plant materials, consists mainly of cellulose and lignin and that is why it is vulnerable to decomposition. It is our common sense and our basic intuition that have advised us for millennia with regard to how to keep organic materials, such as wood, when used in construction, away from water. Nothing can go wrong if we apply the same knowledge to straw.

Appendix 2

FREQUENTLY ASKED QUESTIONS

What about mice and rats?

There is no greater risk of encouraging mice and rats into your strawbale house than there is for any other type of building. Straw is the empty stem of a baled grain crop and, unlike hay, it doesn't contain food to attract furry creatures. Any home where food is left out in the open is a potential lure for vermin. Once your strawbale house is plastered, the walls seem no different from other plastered walls to a mouse. Mice and rats like to live in spaces between things, as they are very sociable animals. In barns, they live in the gaps between bales and in houses they live in cavities and under floors. If you build straw walls and then clad them in timber, with an air gap between, this might attract mice: but it's the gap they like, not particularly the straw. If you build straw walls, plaster them with clay or lime and maintain them; then there are no gaps to invite mice or rats in, and no cavities in which they can live.

How long will it last?

No one can completely answer this question, because the first strawbale house was built only about 140 years ago. In the USA there are about a dozen houses about 100 years old that are still inhabited and showing no problems. They have an increasing stock of houses built since 1980 that are also enduring with no problems. Here in the UK we started building in 1994, and in Ireland in 1996. As with any other technique of house building, if your strawbale house is constructed with a good design, with quality work and is properly maintained throughout its life, there is no reason why it should not last at least 100 years.

Isn't it a fire risk?

No. It may seem strange, but when you stack bales up in a wall and plaster them either side, the density of the bales is such that there isn't enough air inside the bales for them to burn. It's like trying to burn a telephone directory – loose pages burn easily, but the whole book won't catch fire. Strawbale walls have passed all the fire tests they have been subjected to in the USA and Canada. And, regardless of whether the bales themselves are a risk, if you plaster any wall with a half inch of plaster it gives sufficient fire protection to satisfy Building Regulations. In fact, plastered strawbale walls are so low-risk

that they are now being used as fire walls between semi-detached houses.

Is it really cheap to build?

It depends entirely on your approach to building. If you can put lots of time into collecting recycled materials, or do the drawings yourself and keep the design simple, or organise training workshops to build the walls and plaster them, or get your friends and family to help, then yes, it can be cheap to build. For most people, it is more sensible to think of doing the simple bits yourself (initial design, foundation, straw and plaster), and employing others to do the rest (carpentry, roofing, plumbing and electrics). A small office in the garden might cost £35,000 (although substantially less with recycled materials and volunteer labour), and a three-bedroomed house could be £100,000. Affordable council houses are currently being built for a maximum of £110,000, maybe less. Savings are greater on bigger buildings.

Will it be warm and cosy?

Yes, if you also insulate all the parts of it that aren't made of straw to the same standard of thermal efficiency. Obviously, if you build a strawbale house but don't insulate the roof very well, or build a well-insulated house and then leave all the windows open in winter, it won't be warm. And if you build a well-insulated house but it faces north or has no sunlight entering it to warm it up passively, and no other form of heating, then it also might not be warm. Usually we would design a building so that it gained as much heat as necessary from direct sunlight (while protecting it from too much summer sun and over-heating), so that the extra heat you need to add (and pay for) is little or nothing. A very well-insulated building would not lose this heat unless you encouraged it to by opening windows and doors. In general, a well-insulated strawbale house will need a minimal amount of heat in winter, and we'd recommend you open windows now and again for health and ventilation.

Can I do it myself?

Yes, parts of a strawbale house are quite easy to build. Other parts, such as roofing and carpentry, are more difficult. It depends on how much time, determination and dedication you have. But the straw building technique is simple, straightforward and accessible to almost anyone. Most self-builders take a couple of years to build their own house, working most of the time on it: it's a slower process than having a contractor doing it for you.

What if some of my bales do get wet?

It depends on where, and how badly. Generally, if a bale gets wet through the top or bottom into the centre, then it will not dry out before it starts rotting, unless you make holes in it to provide ventilation. So any bales that are rained on, or stand in water while in storage, should be discarded. This also applies to any bales already in the walls that are not covered against the rain. But if you have covered the tops of the bales, and the sides get wet from the rain, this usually

presents no problem, as they will quickly dry out once the rain stops. The only time this may not be the case is if the walls are exposed to severe wind and rain at the same time for prolonged periods, as the wind may drive the rain into the bale, where it cannot dry out.

Is it possible to repair straw walls?

It is not only possible, it's very easy! The hardest part is making a hole through the straw. This can be done with the claw on a hammer or crowbar, and by just pulling at the straw. It can be quite difficult to make the first hole, due to the density of the bale. However, once this is done, wedges of the bales can be pulled out quite easily. Hazel pins can be cut through if necessary, and fresh straw wedges can be packed tightly back to fill the gap.

Experience has shown that if a section of wall does get wet, damp remains remarkably localised. It tends *not* to spread further through the straw, and so wedges or flakes of the bale can be removed and replaced.

What if I want an extra window?

Again, it's fairly easy to cut through the walls to create a window-sized hole. Usually there is no need to support the rest of the wall as the wall plate carries most of the load of the floor above, and the straw bales act together as an integral material because of the way they are pinned. Either follow the method described on the left for repairing straw walls, or you can use a hay knife, even a chainsaw, although power tools like this tend to clog up very quickly. Once you've cut the hole, a structural box frame can be fixed into the gap, with the window inside this.

Can I use straw to add an extension to my house?

Yes, both loadbearing and framed systems work well here. You may need to think carefully about settlement, and not make the final attachments from the straw to the house wall until after the walls are compressed.

You can also easily add an extension to your strawbale house by cutting a doorway through, in the same way as described above for making a window. Families have sometimes encouraged their children to build their own add-on spaces once they've reached a suitable age!

Can I insulate my existing house with straw?

It's perfectly possible to wrap your existing house in straw to give it better thermal efficiency. You will need to extend the roof over the top, and add a small foundation for the straw, plus think carefully about details around windows and doors, but you could transform your ugly concrete bungalow into one that looks like a beautiful old Devon cottage – at least from the outside! It will reduce your heating costs while increasing your comfort.

What if I don't want to build it myself?

There are some companies (such as amazonails) or individuals who can do this for you, or you could work together with a local building contractor. Or you can buy a small strawbale building 'off the peg' and have it delivered!

What about temporary buildings?

The design of strawbale buildings is very versatile, and can be adapted for a more or less durable function. If a building is required for only a few years, then there may be no need to build elaborate foundations, or plaster it inside or even outside. Or you can buy an off-the-peg building and sell it on when you've finished with it.

What else can be built with straw?

Straw has been put to many uses. Apart from houses, studios, offices and community spaces, straw is also used for schools, warehouses, retail units, holiday homes, salerooms, restaurants, barns and stables, sound studios, meditation centres, acoustic barriers for airports and motorways, food storage and farm buildings.

This wonderful circular extension is linked to the main headquarters of the Ecology Building Society in Silsden, West Yorkshire. *Photograph © Rae Parkinson*

Appendix 3

RESOURCES AND RESEARCH

Books, DVDs and websites

Books

Strawbale building

Bingham, W. and Smith, C. (2007) ***Strawbale Home Plans***. Gibbs Smith Publisher, Utah, USA.

Corum, N. (2005) ***Building a Straw Bale House: The red feather construction handbook***. Princeton Architectural Press, New York, USA.

Gray, A.T. and Hall, A. (2000) ***Strawbale Homebuilding***. Earth Garden Books, Victoria, Australia.

Haggard, K. and Clark, S. (2000) ***Straw Bale Construction Detail Book.*** California Straw Bale Building Association.

Hollis, M. (2005) ***Practical Straw Bale Building***. Landlinks Press, Victoria, Australia.

Jones, B. (2009) ***Building with Straw Bales: A practical guide for the UK and Ireland*** (revised edition). Green Books, Devon.

King, B. et al. (2006) ***Design of Straw Bale Buildings: The state of the art***. Green Building Press, California, USA.

King, B. (1996) ***Buildings of Earth and Straw***. Ecological Design Press; distributed by Chelsea Green Publishing, Vermont, USA.

Lacinski, P. and Bergeron, M. (2000) ***Serious Straw Bale.*** Chelsea Green Publishing, Vermont, USA.

Law, B. (2006) ***The Woodland House***. Permaculture Press, London.

Macdonald, S. O. and Myhrman, M. (1997) ***Build it with Bales***. Chelsea Green Publishing, Vermont, USA.

Magwood, C. and Mack, P. (2000) ***Straw Bale Building***. New Society Publishers, Ontario, Canada.

Magwood, C., Mack, P. and Therrien, T. (2005) ***More Straw Bale Building***. New Society Publishers, Ontario, Canada.

Magwood, C. and Walker, C. (2001) ***Straw Bale Details***. New Society Publishers, Ontario, Canada.

Minke, G. and Mahlke, F. (2005) ***Building with Straw***. Birkhauser, Switzerland.
Roberts, C. (2002)

A House of Straw. Chelsea Green Publishing, Vermont, USA.

Steen, A. S., Steen, B. and Bainbridge, D. (1994) ***The Straw Bale House***. Chelsea Green Publishing, Vermont, USA.

Steen, A. S. and Steen, B. (2000) ***The Beauty of Straw Bale Homes***. Chelsea Green Publishing, Vermont, USA.

Steen, B., Steen, A. S. and Bingham, W. J. (2005) ***Small Straw Bale***. Gibbs Smith Publisher, Utah, USA.

Wanek, C. (2003) ***The New Strawbale Home***. Gibbs Smith Publisher, Utah, USA.

Renders and plasters

Guelberth, C. R. and Chiras, D. (2003) ***The Natural Plaster Book***. New Society Publishers, British Columbia, Canada; distributed by Consortium Book Sales and Distribution, Minneapolis, USA.

Holmes, S. and Wingate, M. (2002) ***Building with Lime: A Practical Introduction***. Practical Action Publishing, Rugby, Warwickshire.

Schofield, J. (1998) ***Lime in Building: A Practical Guide***. Black Dog Press, Devon.

Soens, M. (2005) ***Italian Plaster Techniques***. Sterling Publishing, New York, USA.

Weismann, A. and Bryce, K. (2008) ***Using Natural Finishes***. Green Books, Devon.

Other inspirational books

Anderson, W. (2007) ***Green Up: An A-Z of environmentally friendly home improvements***. Green Books, Devon.

Bee, B. (1998) ***The Cob Builder's Handbook***. Groundworks, Oregon, USA. Available from www.beckybee.net.

Easton, D. (2007) ***The Rammed Earth House*** (2nd edn). Chelsea Green Publishing, Vermont, USA.

Evans, I., Smith, M. G. and Smiley, L. (2002) ***The Hand-sculpted House: A practical guide to building a cob cottage***. Chelsea Green Publishing, Vermont, USA.

Kahn, L. (2004) ***Home Work: Handbuilt shelter***. Shelter Publications, California, USA.

Kahn, L. and Easton, B. (2000) ***Shelter***. Shelter Publications, California, USA.

Khalili, N. (2002) ***Ceramic Houses and Earth Architecture: How to build your own***. Chelsea Green Publishing, Vermont, USA.

McCloud, K. (2009) ***Grand Designs Handbook: The blueprint for building your dream home***. HarperCollins, London.

Norton, J. (1997) ***Building With Earth***. Practical Action Publishing, Rugby, Warwickshire.

Plowright, T. (2007) ***Eco-centres and Courses***. Green Books, Devon.

Taylor, J. S. (2008) ***Shelter Sketchbook***. Chelsea Green Publishing, Vermont, USA.

Weismann, A. and Bryce, K. (2006) ***Building with Cob***. Green Books, Devon.

Journals

Green Building Bible. How to make our homes, buildings and living environments greener and more energy-efficient. www.greenbuildingbible.co.uk.

Green Building Magazine. Useful, practical and honest information regarding sustainable and healthy building. www.greenbuildingmagazine.co.uk.

The Green Directory. Published in the UK annually as a book version and also online, this offers a unique blend of people, organisations and businesses involved in the green sectors. www.greendirectory.net/about.htm.

The Last Straw. The international journal of strawbale and natural building since 1993. Published in the USA in pdf and hard-copy format. www.strawhomes.com.

Network. Free AECB (the Sustainable Building Association) newsletter. Regular updates on AECB activities and projects as well as a digest of news on general sustainability issues. www.aecb.net/network.php.

Positive News. A quarterly international newspaper promoting individuals and enterprises that are working to create a more healthy, humane and environmentally sustainable world. www.positivenews.org.uk.

Resurgence magazine. Publishes articles that are on the cutting edge of current thinking, promoting creativity, ecology, spirituality and frugality. www.resurgence.co.uk.

Sustainability. The practical journal for green building, renewable energy, permaculture and sustainable communities. Published in Ireland. www.sustainability.ie.

DVDs

Building with Awareness by Ted Owens. The step-by-step construction of a strawbale house in the USA. Available from www.buildingwithawareness.com.

Built of Straw. An Outwood Community film following the construction of a strawbale allotment building in Wakefield, West Yorkshire.
Available from www.amazonails.org.uk.

Houses of Straw. The rediscovery of strawbale building, by Heidi Schnell. This film shows the recent development of this building method, mainly in Germany. Contains voice-over language versions in English, French, German and Spanish. Available from www.oekofilm.de/index.php?id=20,33,0,0,1,0.

Videos

Building with Straw, vols 1, 2 and 3 by Black Range Films. Learn the basics of strawbale construction, see examples of houses and learn about test results. Available from www.strawbalecentral.com.

Websites

The following websites contain updated resources relevant to strawbale building.

www.amazonails.org.uk

www.cc-w.co.uk/SB_Resources.htm
Conservation Consultants (worldwide) Ltd, Cornwall.

http://en.wikibooks.org/wiki/Straw_Bale_Construction

www.greenbooks.co.uk
An independent, environmental UK publishing company.

www.greenbuildingpress.co.uk

www.greenspec.co.uk
A directory of sustainable construction products and contact details of manufacturers and suppliers.

http://mha-net.org/html/sblinks.htm
Surfin' Strawbale – an eclectic compendium of useful knowledge on strawbale building globally.

www.naturalhomes.org
A resource for finding courses and workshops related to natural home building worldwide.

www.strawbale-building.co.uk

www.strawbalecentral.com

www.sustainablebuild.co.uk
A reference point for sustainable building, development and eco-construction techniques.

www.thelaststraw.org/backissues.html

www.thelaststraw.org/resources

www.walnutbooks.com
Ireland's sustainable booksellers.

UK and Ireland organisations and suppliers

Organisations

Alternative Technology Centre (ATC)
Hebden Bridge, W. Yorks
01422 842121
www.alternativetechnology.org.uk
Shop and workshops on eco-friendly energy, recycling and lots more.

amazonails
Todmorden, W. Yorks
0845 458 2173
www.amazonails.org.uk
A not-for-profit social enterprise providing strawbale and natural building design, consultancy and training.

British Hay and Straw Merchants Association
Huntingdon, Cambs
01487 830980
www.hay-straw-merchants.co.uk
Trade organisation, which lists straw suppliers.

Building Limes Forum (BLF)
Edinburgh
www.buildinglimesforum.org.uk
A charitable organisation founded in 1992 to promote the development of expertise and understanding in the use of lime in building.

Building Limes Forum Ireland (BLFI)
Dublin, Ireland
www.buildinglimesforumireland.com
Voluntary organisation affiliated with the BLF UK, for members in both Northern Ireland and the Republic of Ireland.

Centre for Alternative Technology (CAT)
Machynlleth, Powys
01654 705950
www.cat.org.uk
Visitor and residential centre offering free information service and a wide range of courses, events for schools, etc.

Centre for Environmental Living and Training (CELT)
Scariff, Co. Clare, Ireland
00 353 (0)61 640765
www.celtnet.org
A registered charity dedicated to environmental awareness, education and training.

Cultivate – living and learning centre
Dublin, Ireland
00 353 (0)1 674 5773
www.cultivate.ie
Information, shop, courses and events.

Environmental and Sustainable Construction Association (ÉASCA)
Dublin, Ireland
00 353 (0)1 674 5773
www.easca.ie
Promotes the viability of sustainable construction in Ireland.

The Green Register
Bristol
0117 377 3490
www.greenregister.org.uk
An independent organisation whose goal is to promote sustainable building practices across all disciplines of the construction industry.

Low Impact Living Initiative (LILI)
Wilmslow, Bucks
01296 714184
www.lowimpact.org
A not-for-profit organisation that aims to help people reduce their impact on the environment, improve their quality of life and gain new skills.

National Non-Food Crops Centre (NNFCC)
Heslington, York
01904 435182
www.nnfcc.co.uk
The UK's National Centre for renewable materials and technologies. Provides independent advice and information to industry, government and the general public.

The Organic Centre
Rossinver, Co. Leitrim, Ireland
00 353 (0)71 985 4338
www.theorganiccentre.ie
Promotes organic gardening and sustainable living through information, training and demonstration.

The Scottish Lime Centre
Charlestown, Fife
01383 872722
www.scotlime.org
Promotes traditional building skills and provides advice and training in the use of lime.

Society for the Protection of Ancient Buildings (SPAB)
London
020 7377 1644
www.spab.org.uk
A membership organisation fighting to save historic and listed buildings from decay, demolition and destruction.

Sonairte
Laytown, Co. Meath, Ireland
00 353 (0)41 982 7572
http://sonairte.org

An interactive visitor centre promoting ecological awareness and sustainable living.

The Sustainable Building Association (AECB)
LLandysul, Powys
0845 4569773
www.aecb.net
Promotes environmentally responsible practices within building. Has a forum, e-newsletter and magazine.

Women And Manual Trades (WAMT)
London
020 7251 9192
www.wamt.org
The national organisation for tradeswomen and women training in the trades.

Suppliers

Black Mountain Insulation
Rhyl, Denbighshire
01745 361911
www.blackmountaininsulation.com
Welsh sheepswool insulation.

Cornerstone Ltd
Kilcock, Co. Kildare, Ireland
00 353 (0)50 347816
Lime manufacturers and training.

EcoBuild
New Ross, Co. Wexford, Ireland
00 353 (0)51 445099
www.ecobuild.ie
Green building products.

Ecological Building Systems
Athboy, Co. Meath, Ireland
00 353 (0)46 943 2104
www.ecologicalbuildingsystems.com
Outlet for sustainable building materials.

Ecomerchant Ltd
Goodnestone, Kent
01795 530130
www.ecomerchant.co.uk
Environmental builders' merchant.

Econstruction products
Rathcoole, Co. Dublin, Ireland
00 353 (0)1 401 9729
www.econstructionproducts.ie
Eco-friendly building materials.

Ed Byrne
Tullow, Co. Carlow, Ireland
00 353 (0)59 915 1750
Lime supplier and consultancy.

Green Building Store
Huddersfield, W. Yorks
01484 461705
www.greenbuildingstore.co.uk
Products for energy-efficient, sustainable and healthy buildings.

Hay-net.com
Letchworth, Herts
01462 674853
www.hay-net.com
Straw and hay 'marketplace' linking buyers and sellers.

Hempire Ltd
Clones, Co. Monaghan, Ireland
00 353 (0)47 52049
Limavady, Belfast, N. Ireland
028 7776 9794
www.hempirebuilding.co.uk
For hemp and lime products.

The Lime Centre
Winchester, Hampshire
01962 713636
www.thelimecentre.co.uk
Materials, courses and consultancy on building with lime.

Lime-Green Ltd
Much Wenlock, Shropshire
01952 728611
www.lime-green.co.uk
Healthy materials for balanced buildings.

Limetechnology
Abingdon, Oxfordshire
0845 603 1143
www.limetechnology.co.uk
Sustainable low-carbon lime-based building systems for mainstream construction.

Lochplace Building Conservation
Innishannon, Co. Cork, Ireland
00 353 (0)21 477 6677
www.lochplace.com
Specialists in traditional building materials and services.

Mike Wye and Associates
Buckland Filleigh, Devon
01409 281644
www.mikewye.co.uk
Suppliers of natural building and decorating products.

Narrow Water Lime Service
Warrenpoint, Co. Down, N. Ireland
028 417 53073
Suppliers of lime mortar, consultancy and training.

Natural Building Technologies (NBT)
Oakley, Buckinghamshire
01844 338338
www.natural-building.co.uk
A technical sales company for sustainable building materials and systems for the mainstream construction market

Second Nature
Penrith, Cumbria
017684 86285
www.secondnatureuk.com
English sheepswool insulation.

Sheepwool Insulation
Rathdrum, Co. Wicklow, Ireland
00 353 (0)40 446100
www.sheepwoolinsulation.ie
Thermal and acoustic products from sheepswool.

The Traditional Lime Company
Cheltenham, Gloucestershire
01242 525444
www.traditionallime.co.uk
Traditional and hydraulic lime.

Traditional Lime Company
Tullow, Co. Carlow, Ireland
00 353 (0)50 351750
Natural hydraulic limes. Not related to the above company by the same name.

Ty Mawr Ecological Building Materials
Brecon, Powys
www.lime.org.uk
Eco-friendly and traditional building materials.

Womersleys Ltd
Heckmondwike, W. Yorks
01924 400651
www.womersleys.co.uk
Eco-friendly materials and building products.

Building Control

www.cic.org.uk/services/AIregister.shtml
The Construction Industry Council's Approved Inspectors Register. Order by phone on 020 7399 7400.

jha innovation (jhai)
www.approvedinspector.com
Corporate Building Control Approved Inspectors with significant strawbale building experience. See website to find your nearest office.

Engineers with strawbale building experience

Paul Rose Consulting Engineers
Halifax, W. Yorks
01422 348985

Structural Solutions
Bristol
0117 924 5014
www.structuralsolutions.co.uk

Europe and North America resources

amazonails ambassadors

These are people who have undergone training with amazonails to become trainers in their own right.

Czech Republic

Jakub Wihan. Todmorden, W. Yorks and Prague
Strawbale building, lime and clay plastering, moisture management in straw, design and training.
www.jakubwihan.com,
kuba@jakubwihan.com

Germany

Friederike Fuchs, architect. Stroh Unlimited, Berlin
Strawbale, clay and lime design, build, engineering and training.
www.stroh-unlimited.de/int/engl.htm,
mail@stroh-unlimited.de

Italy

Stefano Soldati. La Boa Permaculture Centre, Nr Venice
Strawbale building, lime and clay plastering, training and design. www.laboa.org,
casadipaglia@hotmail.com

Spain

Maren Termens
Technical architect for ecological buildings, strawbale and clay training.
www.tallerdepalla.org,
autoconstruccin@yahoo.es

Rikki Nitzkin
Strawbale and clay training.
rikkinitzkin@earthlink.net

Europe

The European strawbale mailing list
http://amper.ped.muni.cz/mailman/listinfo/strawbale
The European alternative to the Crest strawbale mailing list in the USA (see page

152), in English with separate French and Spanish listings.

Strawbale Europe
www.baubiologie.at/europe/

The following are the main in-country websites for strawbale building, which contain further resources themselves.

Austria: **www.baubiologie.at**

Belgium: **www.casacalida.be**

Czech: **www.postavsisam.cz**

Denmark: **www.lob.dk**

Estonia: **www.equilibre.ee**

France: **www.compaillons.fr, www.lamaisonenpaille.com**

Germany: **www.fasba.de**

The Netherlands: **www.strobouw.nl**

Norway: **www.naturligbyggeri.no**

Slovakia: **www.ozartur.sk**

Spain: **www.casasdepaja.org**

Sweden: **www.naturligt-byggeri.org**

Canada

Ontario Strawbale Building Coalition
www.osbbc.ca
Works towards a more environmentally responsible built environment by providing information, supporting research and fostering a community of builders and owners.

USA

Builders Without Borders
www.builderswithoutborders.org
An international network of ecological builders who advocate the use of straw, earth and other local, affordable materials in construction.

The Canelo Project
www.caneloproject.com
A small non-profit organisation dedicated to the exploration and development of living systems, including growing food and building for friendship, beauty and simplicity.

The Development Center for Appropriate Technology
www.dcat.net
Works to enhance the health of the planet and our communities by promoting a shift to sustainable construction and development.

Ecological Building Network
www.ecobuildnetwork.org
Works to transform the way we build shelter.

Natural Building Network
www.nbnetwork.org
A not-for-profit membership association promoting natural building principles, materials and practitioners worldwide.

The Strawbale Building Registry
http://sbregistry.greenbuilder.com
The biggest list of strawbale buildings on the web.

Strawbale Construction Discussion List (Crest)
http://listserv.repp.org/mailman/listinfo/strawbale_listserv.repp.org
List for discussion of strawbale construction techniques, materials, codes and related disciplines.

SB-r–us: Straw Bale Social Club
http://groups.yahoo.com/group/SB-r-us/

Research

General

Australia

Wilson, L. (2007). 'Straw bale wineries: Wallington Wines'. *The Owner Builder* 142, Aug/Sept 2007. Available at www.grossebotte.com/Chantier1/maison3/walhallawinepdf.pdf. Accessed 09/06/09.

Austria

GrAT (2005) *S-House Presentation*. Centre for Appropriate Technology, Vienna University of Technology, Vienna. Available at www.s-house.at/presentation_s_house.pdf. Accessed 09/06/09.

Belarus

Shirokov, Y. (2000) *Building with Straw Bales in Belarus*. International Network for Sustainable Energy. Available at www.inforse.dk/europe/iae/mae/building.html. Accessed 09/06/09.

Canada

Magwood, C. (2004) 'Straw Bale Building: On the cusp of the mainstream'. *Homepower* 101, June & July 2004. Available at www.homepower.com/article/?file=HP101_pg14_Magwood. Accessed 09/06/09.

China

Vuong, L. (2004) *Straw Bale Construction in China: A comparison of obstacles between Northern and Southern rural areas for the use of straw bale construction as an energy efficient building alternative*. University of Puget Sound, P.R.E.M.I.U.M. Program, China. Available at www.osbbc.ca/wordpress/wp-content/uploads/2009/02/strawbale_construction_china.pdf. Accessed 09/06/09.

Czech Republic

Wihan, J. (2004) *Straw Bale Building in the Czech Republic: Overall view*. Presentation for ISBBG 04 in Friland, Denmark. Available at www.jakubwihan.com/doc/isbbc04/isbbc04cz.htm. Accessed 09/06/09.

Pakistan

PAKSBAB (2008) *Straw Bale Fabrication*. Pakistan Straw Bale and Appropriate Building (PAKSBAB), California, USA. Available at www.paksbab.org/imgs/CompMould_Jack_11_19_08.pdf. Accessed 09/06/09.

Siberia

Wihan, J. (2005) *Straw Bale Building in Siberia.* Report for Builders Without Borders, New Mexico, USA. Available at www.jakubwihan.com/pdf/SBinSiberia.pdf. Accessed 09/06/09.

UK

Hilton, R. (2007) *Straw Bale Construction: Is straw bale construction suitable for self-builders in Britain?* A dissertation submitted in partial fulfilment of the degree of M.Arch, Welsh School of Architecture, Cardiff.

USA

Bartels, L. (2008) *Straw Bale Construction: Harvesting its potential as an affordable and energy efficient building strategy.* Environmental and Energy Study Institute Briefing, Washington. Available at http://files.eesi.org/Bartels_062008.pdf. Accessed 09/06/09.

Straw in the UK

BMEC (2008) *Straw*. Biomass Energy Centre, Farnham, Surrey. Available at www.biomassenergycentre.org.uk/portal/page?_pageid=75,17972&_dad=portal&_schema=PORTAL. Accessed 09/06/09.

DEFRA (2008) *Agricultural and Horticultural Survey – England*. Low-level Agricultural Survey Datasets, showing average annual yields. Available at www.defra.gov.uk/esg/work_htm/publications/cs/farmstats_web/2_SURVEY_DATA_SEARCH/COMPLETE_DATASETS/regional_level_datasets.htm. Accessed 09/06/09.

DEFRA (2008) *Regional and County level crop areas*. Excel datasheet available at https://statistics.defra.gov.uk/esg/junesurvey/june_survey.htm. Accessed 05/10/09.

Stott, E. (2003) *Straw Availability in the UK*. BioRegional Development Group, BedZED Centre, Wallington, Surrey. Available at www.nnfcc.co.uk/metadot/index.pl?id=4227;isa=DBRow;op=show;dbview_id=2539. Accessed 09/06/09.

Building Guidelines and Codes

Worldwide

The Last Straw (2006) 'Worldwide Codes and Permitting Update: Links for Straw Bale Codes, Guidelines and Supporting Documentation'. *The Last Straw* No. 54. Available at www.thelaststraw.org/backissues/articles/54-15.pdf. Accessed 09/06/09.

New Zealand

North, G. (2002) *Strawbale Building Guidelines for Wet and Humid Climates (such as New Zealand's).* A paper for the Strawbale Building: Sustainable Technology Renewing the World conference. Available at www.ecodesign.co.nz/strawbale.shtml. Accessed 09/06/09.

Scotland

Walker, G. (2007) *Barriers to Straw Bale Construction in Scotland*. A dissertation submitted in part fulfilment of BSc (Honours) Building Surveying, School of the Built and Natural Environment, Glasgow Caledonian University, Glasgow.

USA

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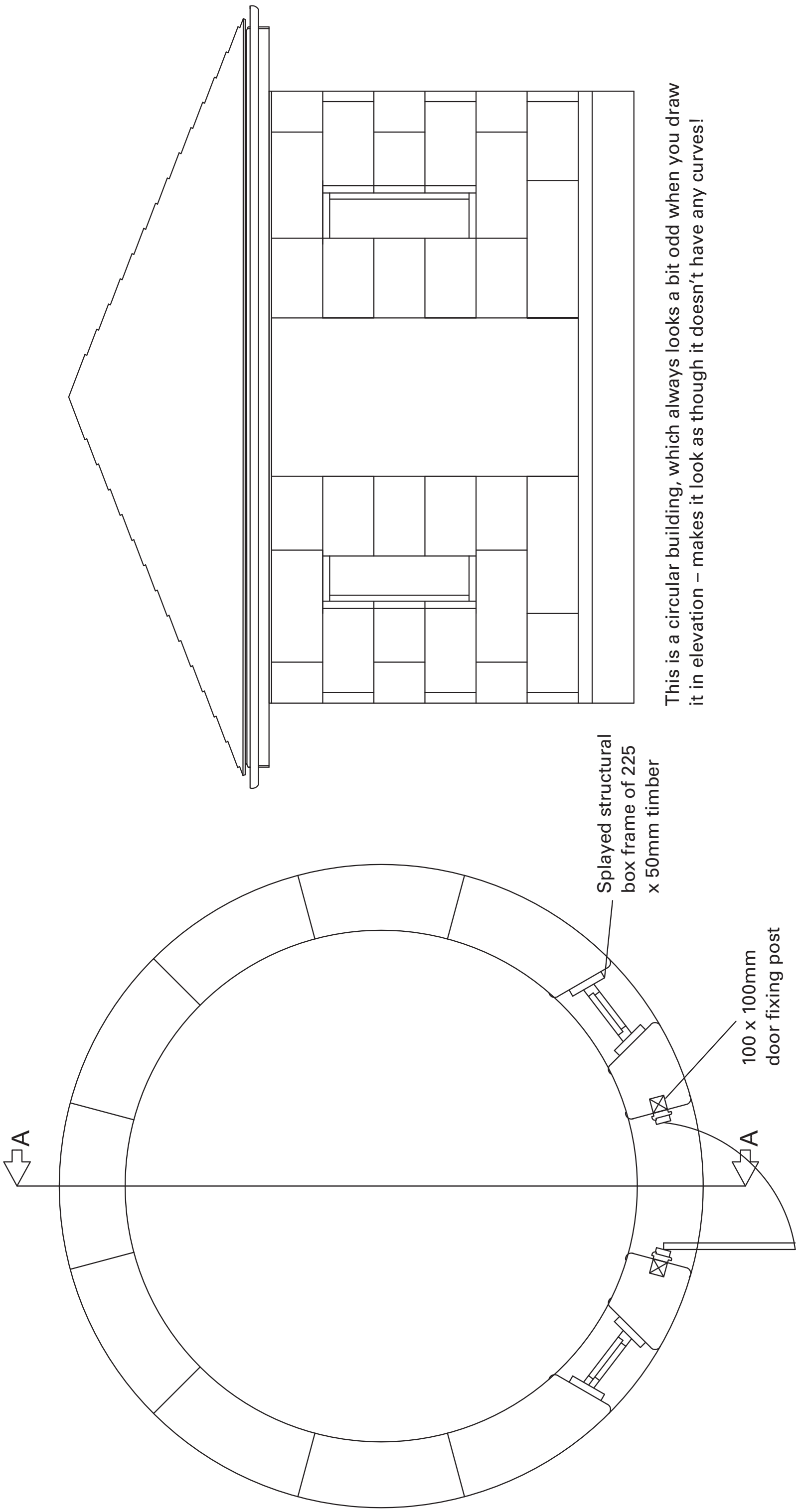
Appendix 4

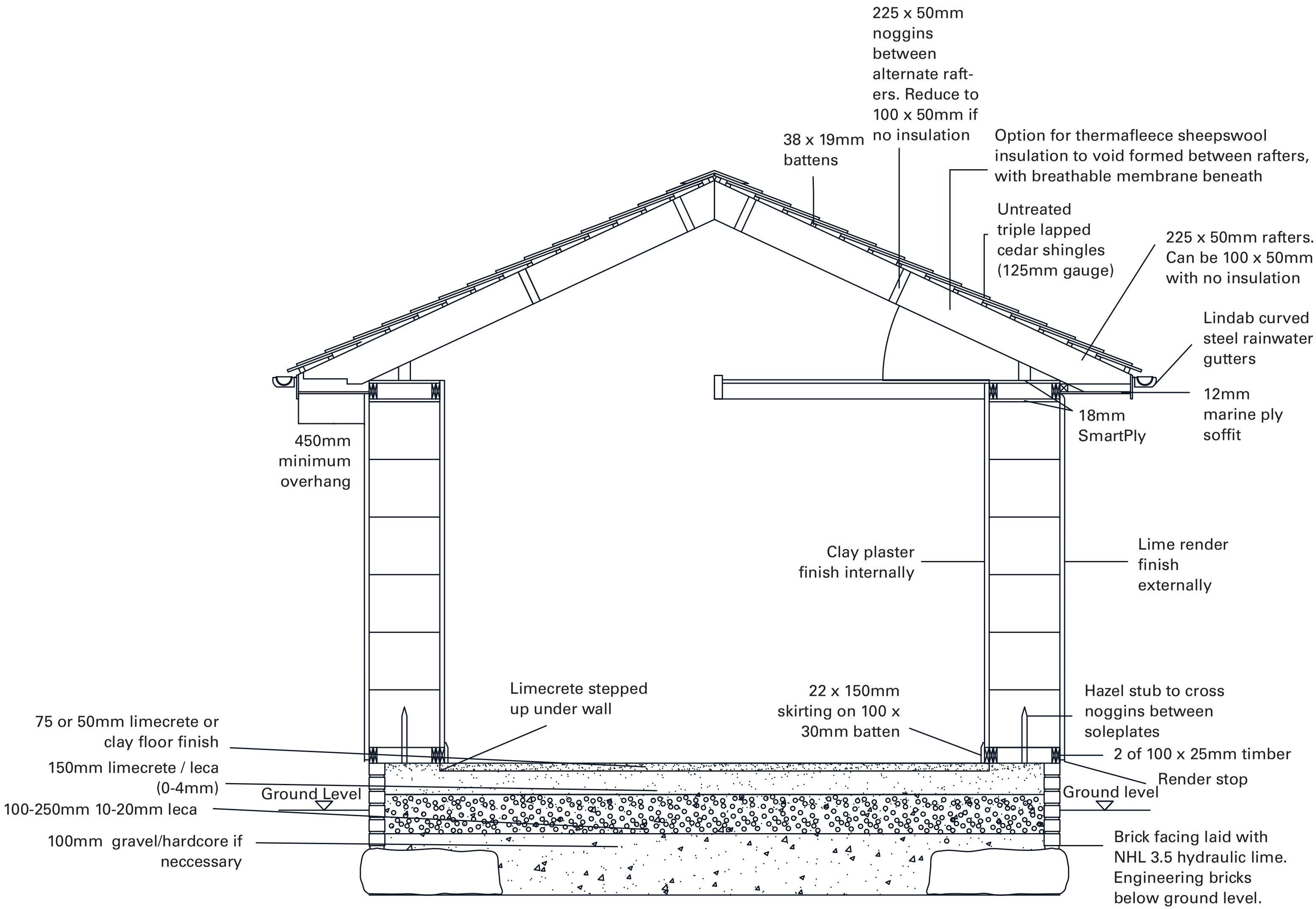
CONSTRUCTION DRAWINGS

The following drawings come from the standard details and drawings developed by amazonails to show best practice in straw-bale building design. They have been developed through practical experience to be as simple as possible, using readily available sustainable materials, while embodying principles of durability and airtightness.

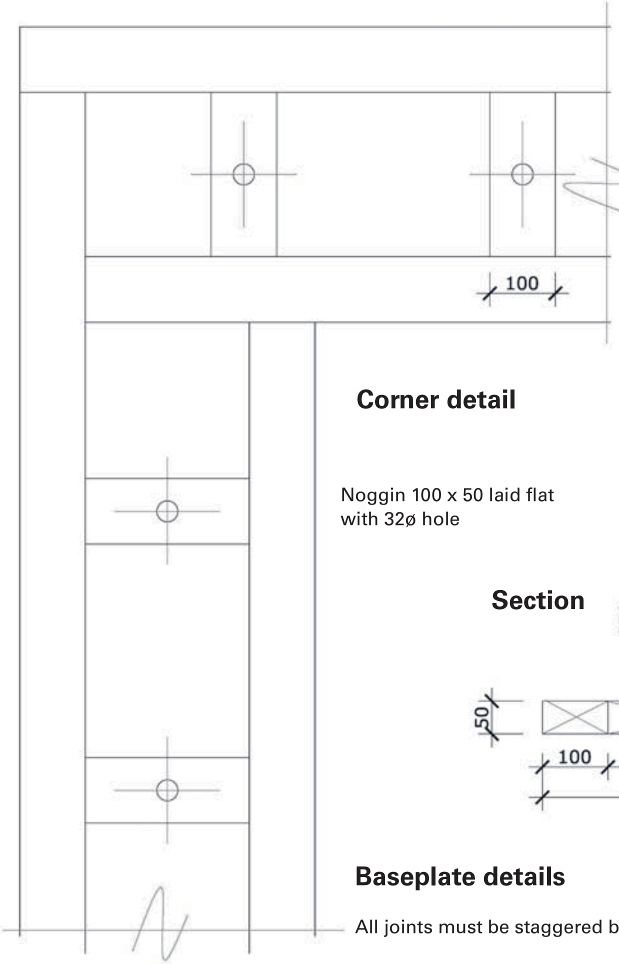
The simple garden building ('Summerhouse') was built by Sue and Richard Nicol. The council houses at Waddington have been built by North Kesteven Council and contractors Taylor Pearson. Both these buildings are pictured in the colour section of this book. All other drawings are taken from amazonails' standard designs.



SIMPLE GARDEN BUILDING, PLAN AND ELEVATION



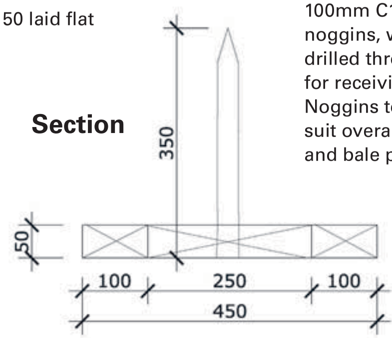
SIMPLE GARDEN BUILDING, CROSS-SECTION



Corner detail

Noggin 100 x 50 laid flat
with 32ø hole

Section



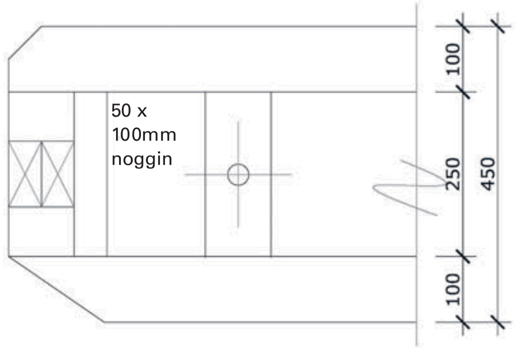
Baseplate details

All joints must be staggered by a minimum of 500mm on a plan

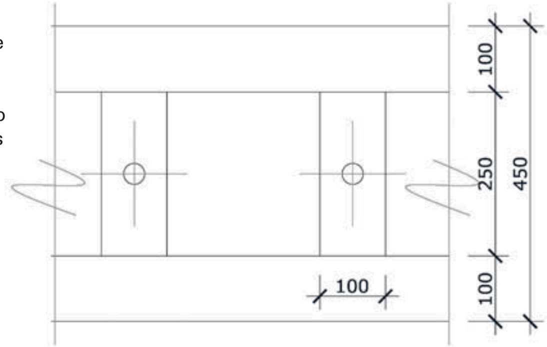
2 No. 50 x 100mm timber posts for door framing support. Shows timber cut back to interior to allow for splay.

Baseplate construction

2 No. 50 x 100mm C16 sw sawn untreated timber joists laid flat, with 50 x 100mm C16 sw timber noggins, with 32mmø hole drilled through noggin for receiving hazel pins. Noggins to be at centres to suit overall strawbale sizes and bale plan layout.

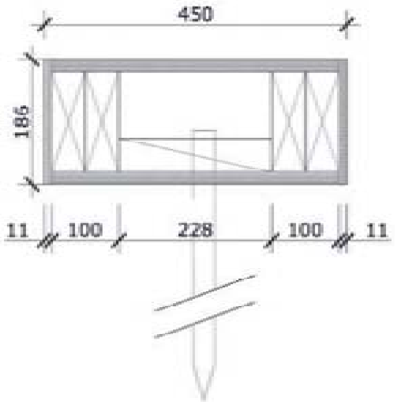


Door opening



Standard detail

STANDARD BASEPLATE CONSTRUCTION



Wallplate/roofplate section

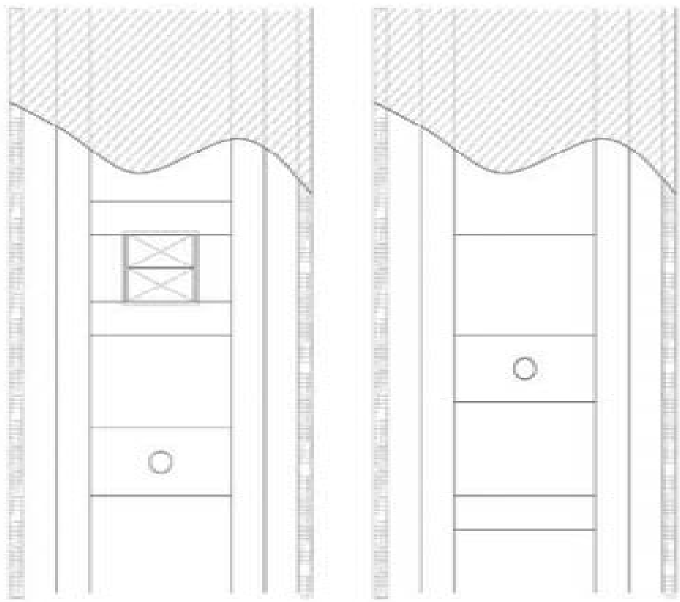
Wallplate/roofplate construction

Form 450 x 186mm wallplate using 2 No. 150 x 50mm C16 timber bearers each side to form continuous roofplate. Glue & screw together. Joints along length of timber to be staggered.

To top & bottom face provide 18mm SmartPly sheathing glued & screwed to timbers.

Provide 11mm SmartPly to cover all timber joins to prevent air ingress, fixed with galvanised nails or similar.

Sheepswool insulation to infill roofplate between all timber to avoid cold bridging.



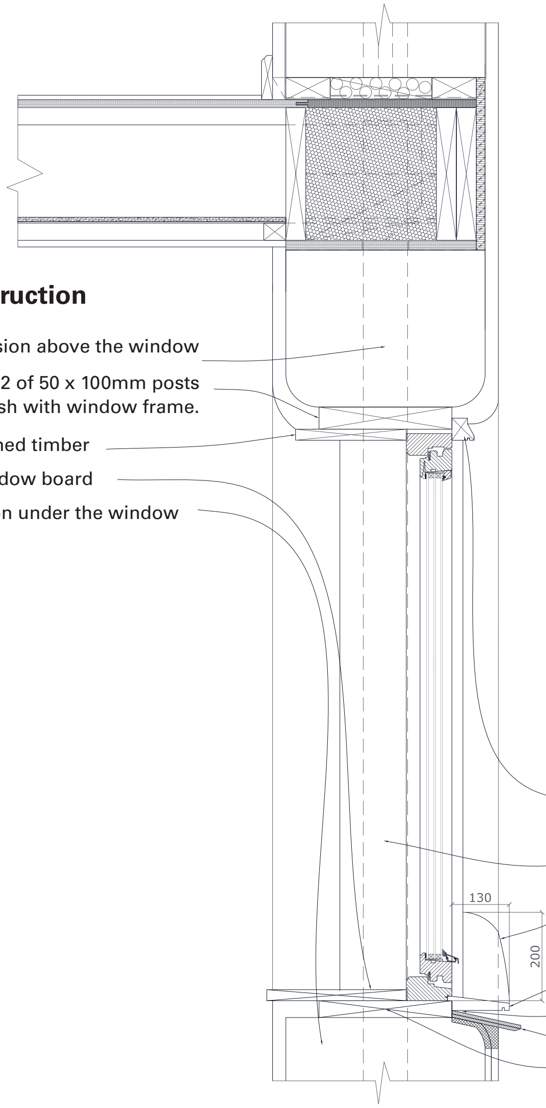
Wallplate/roofplate details

Timber wallplate to be 450mm wide (or bale width if different) comprising:
2 No. 50 x 150mm C24 timber joists forming each side with noggins of 50 x 100mm laid flat at centres to suit top course bale plan drilled with 32ø hole for receiving hazel stubs. Wallplate to be faced top & bottom with 18mm SmartPly and sides faced with 11mm SmartPly to cover all joins.

Wallplate to be flat with ± 5mm tolerance across full length of baseplate.

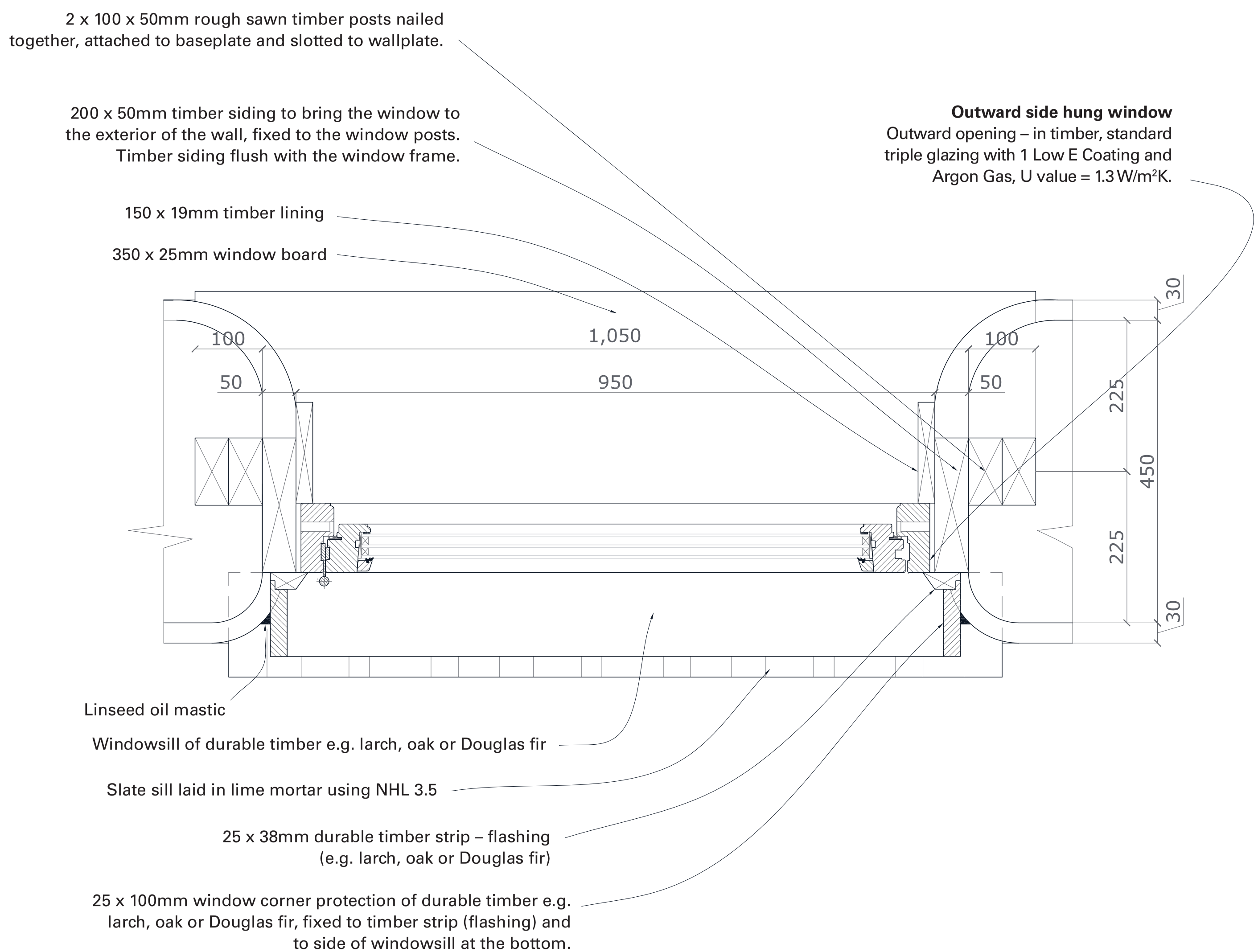
NB. Setting out dimensions of noggins are to be coordinated with the Bale Plan. Should the Bale Plan alter then the noggin locations need to change to match.

Window construction

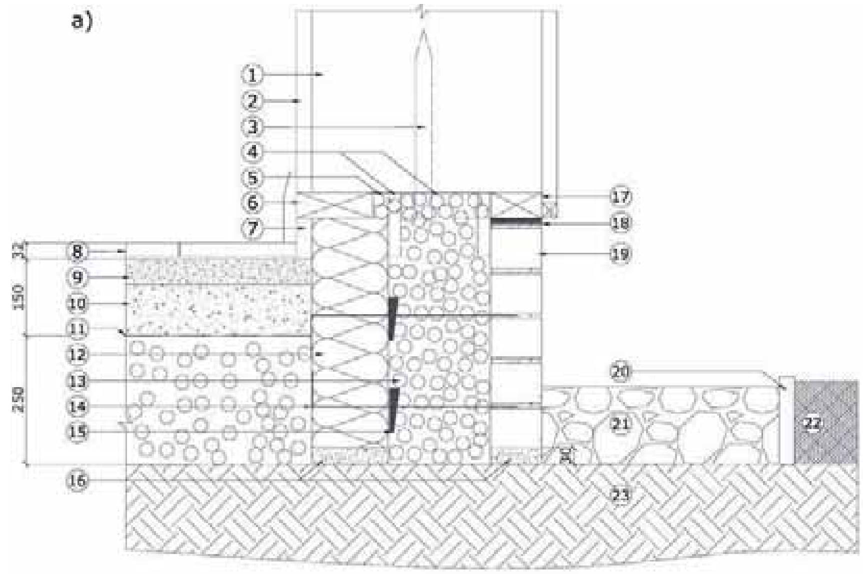


STANDARD WINDOW DESIGN (ELEVATION)

Window construction

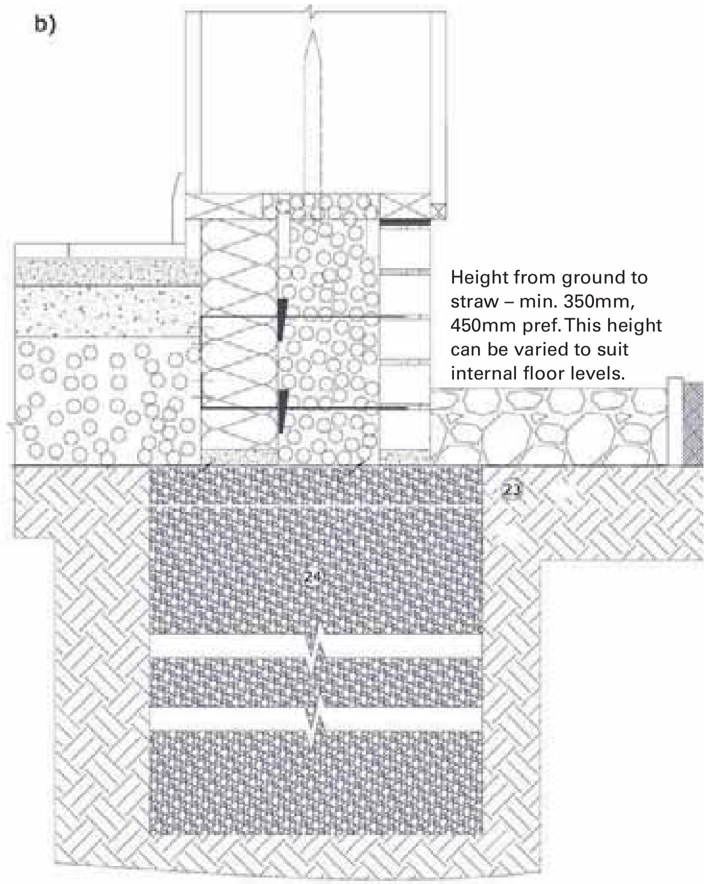


STANDARD WINDOW DESIGN (PLAN)



a) Foundations on good bearing soil, with a solid limecrete floor

1. 450mm strawbale wall
2. 30mm traditional 3-coat lime render with limewash or active mineral paint
3. Hazel stub 32mm diameter x 350mm secured into noggin
4. 50 x 25mm timber to prevent lateral movement of baseplate, at 500mm centres
5. 100 x 50mm noggin in baseplate drilled to accommodate 32mm hazel stub
6. 150 x 50 durable timber e.g. larch, oak, Douglas fir in baseplate
7. Service port
8. Ceramic tiles with lime/sand grout
9. Limecrete 65mm screed, can contain underfloor heating. www.lime.org.uk
10. Limecrete 100mm slab. www.lime.org.uk
11. Geotextile
12. 150 x 450mm foamglas T4 block on edge, compressive strength: 700kN/m^2, drilled to allow for s/s anchors. www.foamglas.co.uk
13. 250mm recycled foam glass or similar loadbearing insulation to achieve self-draining foundation, www.lime.org.uk, www.womersleys.co.uk. This material should be non-porous and acts as a capillary break.
14. s/s wall tie SSF FMR secured to foamglas by screws and wall plugs
15. s/s wedge inserted in tie to secure foamglas
16. 30mm NHL 5 lime mortar
17. 100 x 50mm durable timber in baseplate, e.g. larch, oak, Douglas fir
18. Triple layer of natural slate, as natural damp-proof course and render stop, or 30mm oak render stop
19. Brick plinth wall laid with NHL 3.5 hydraulic lime mortar. Engineering bricks should be used below ground level and to a height of 150mm above.
20. Stone or slate restraint
21. 450mm drainage gravel around wall
22. Topsoil
23. Levelled and compacted ground, topsoil removed



b) Foundation option for wet ground, or made-up ground, with a solid limecrete floor

24. Draining:
washed 40mm limestone gravel or similar, well compacted in 100mm layers
OR 40mm self-levelling gravel or similar, poured to depth no greater than 700mm with limecrete cap of 400mm depth on top
OR local stone laid in NHL 5 hydraulic lime mortar

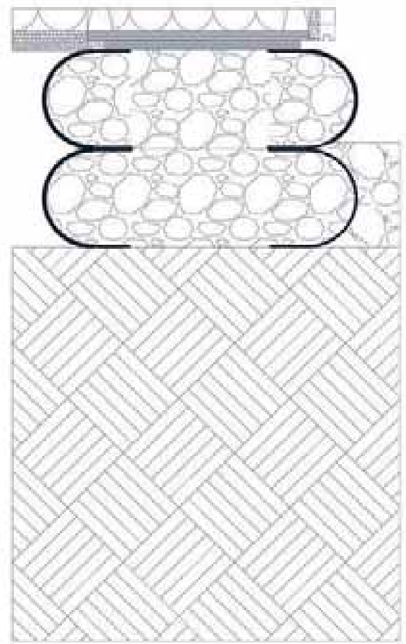
Rising damp & self-draining foundations

Foamglas laid in lime mortar & rfg are non-porous materials that form a capillary break and do not allow moisture to wick upwards from the ground. The use of non-porous materials means that there is no need for a damp-proof course.

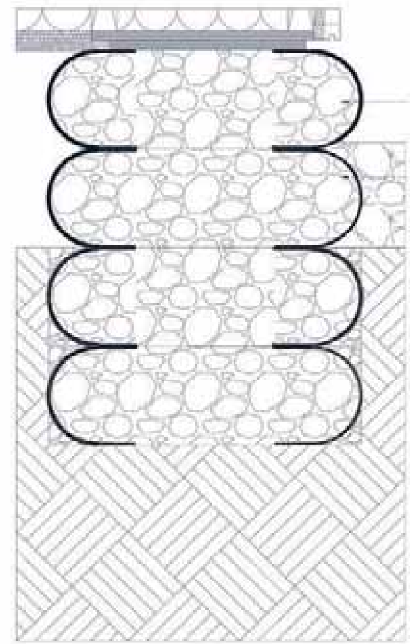
a) Foundation option showing rammed car tyres with suspended timber floor on good bearing soil

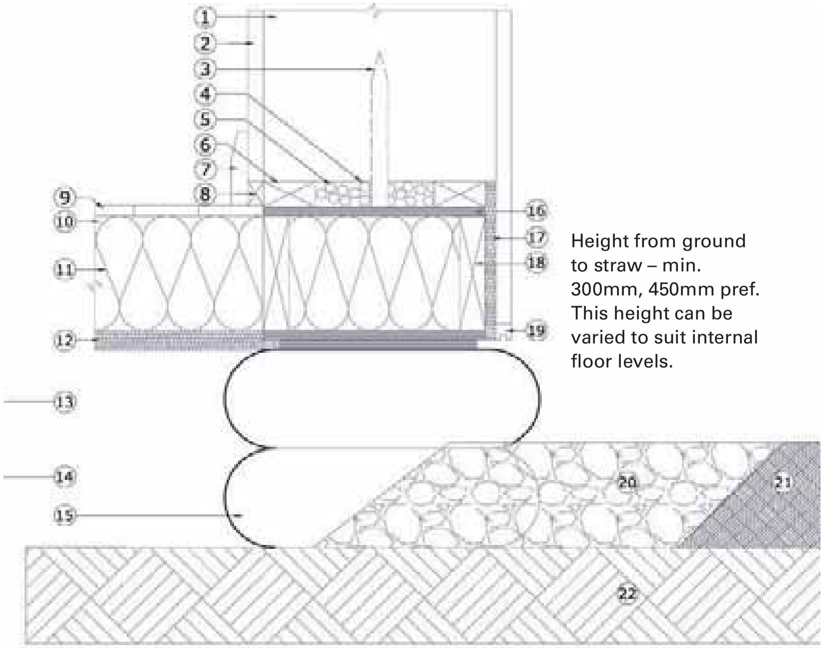
b) Foundation option for clayey soils using car tyres

a)



b)

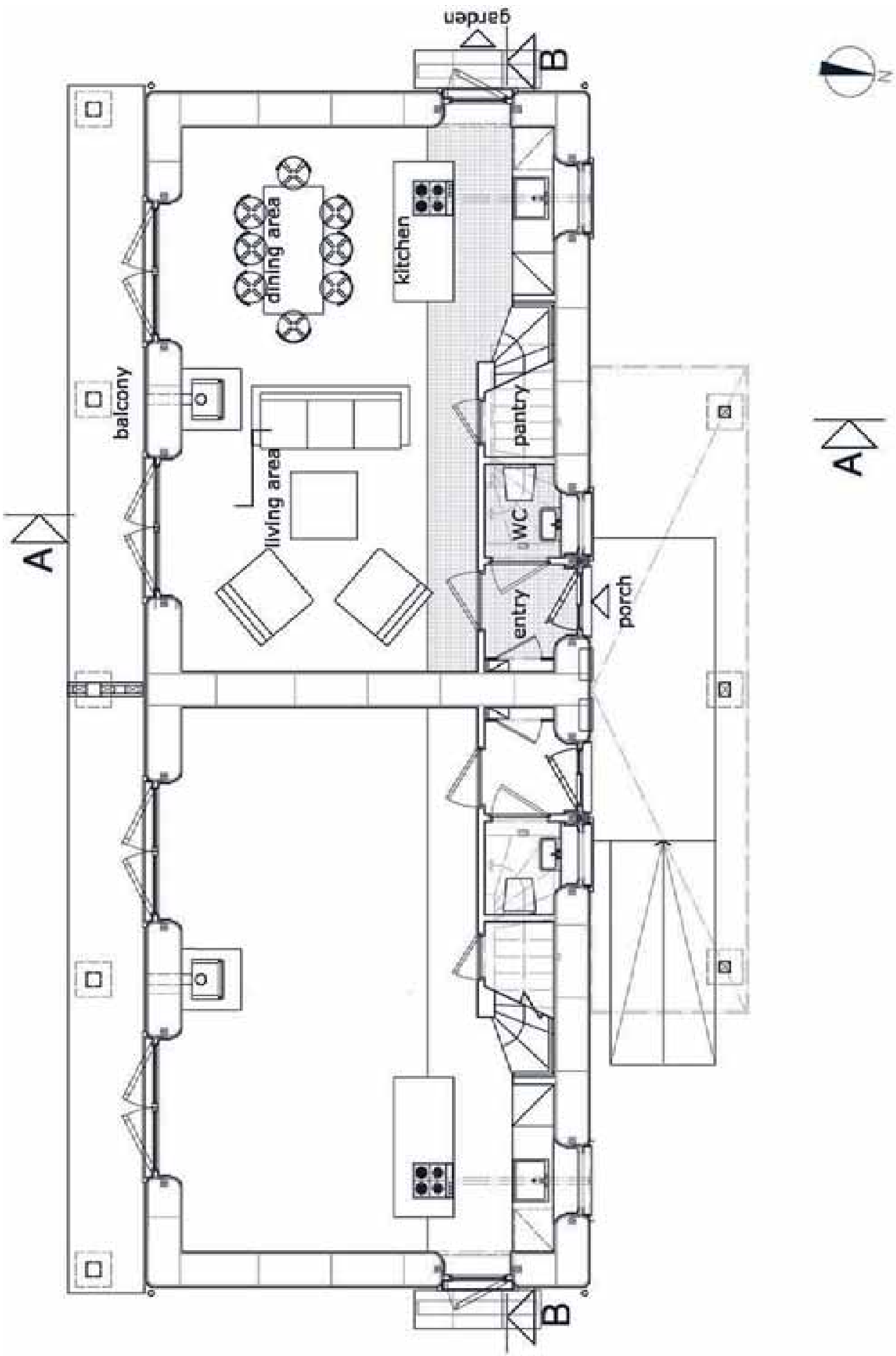




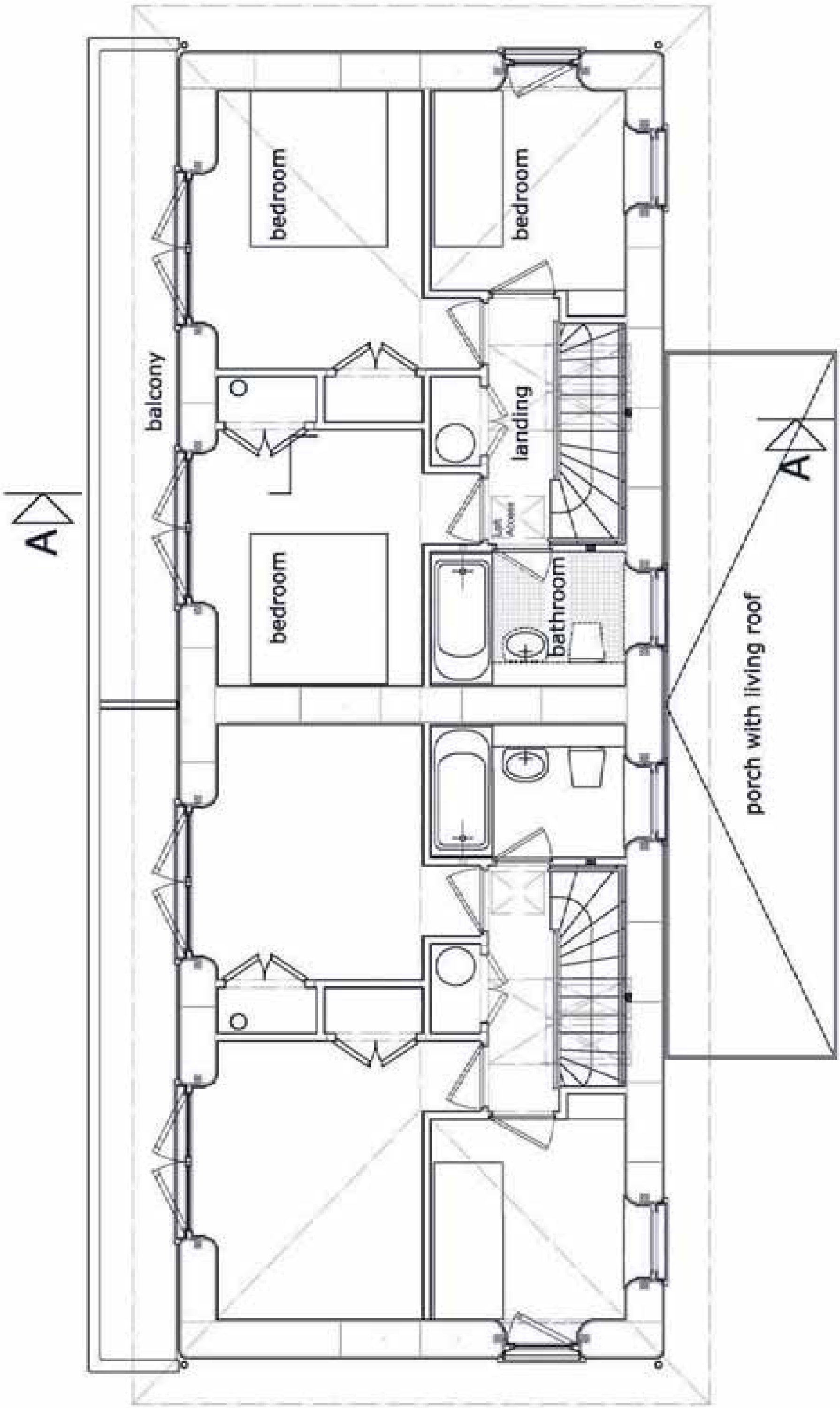
Height from ground to straw – min. 300mm, 450mm pref. This height can be varied to suit internal floor levels.

1. 450mm strawbale wall
2. 30mm traditional 3-coat lime render with limewash or active mineral paint
3. Hazel stub 32mm diameter x 350mm secured into noggin
4. 100 x 50mm noggin in baseplate drilled to accommodate 32mm hazel stub
5. Leca/Optiroc or other self-draining loose-fill insulation
6. 150 x 50mm durable timber in baseplate e.g. larch, oak, Douglas fir
7. Timber skirting
8. Timber@400mm to support skirting
9. Timber flooring
10. 225 x 50mm@400 c/c timber joists
11. 225mm sheepswool insulation
12. 40mm formaldehyde-free wood fibre board to bottom of joists
13. Rammed draining stone fill
14. First tyre completely rammed with 40mm draining stone or similar
15. Number of tyres dependent on depth of topsoil
16. 18mm SmartPly
17. 20mm board as key for plaster
18. 50 x 225mm durable timber e.g. larch, oak, Douglas fir
19. Render stop
20. Gravel to form level ground with topsoil
21. Topsoil
22. Good bearing subsoil

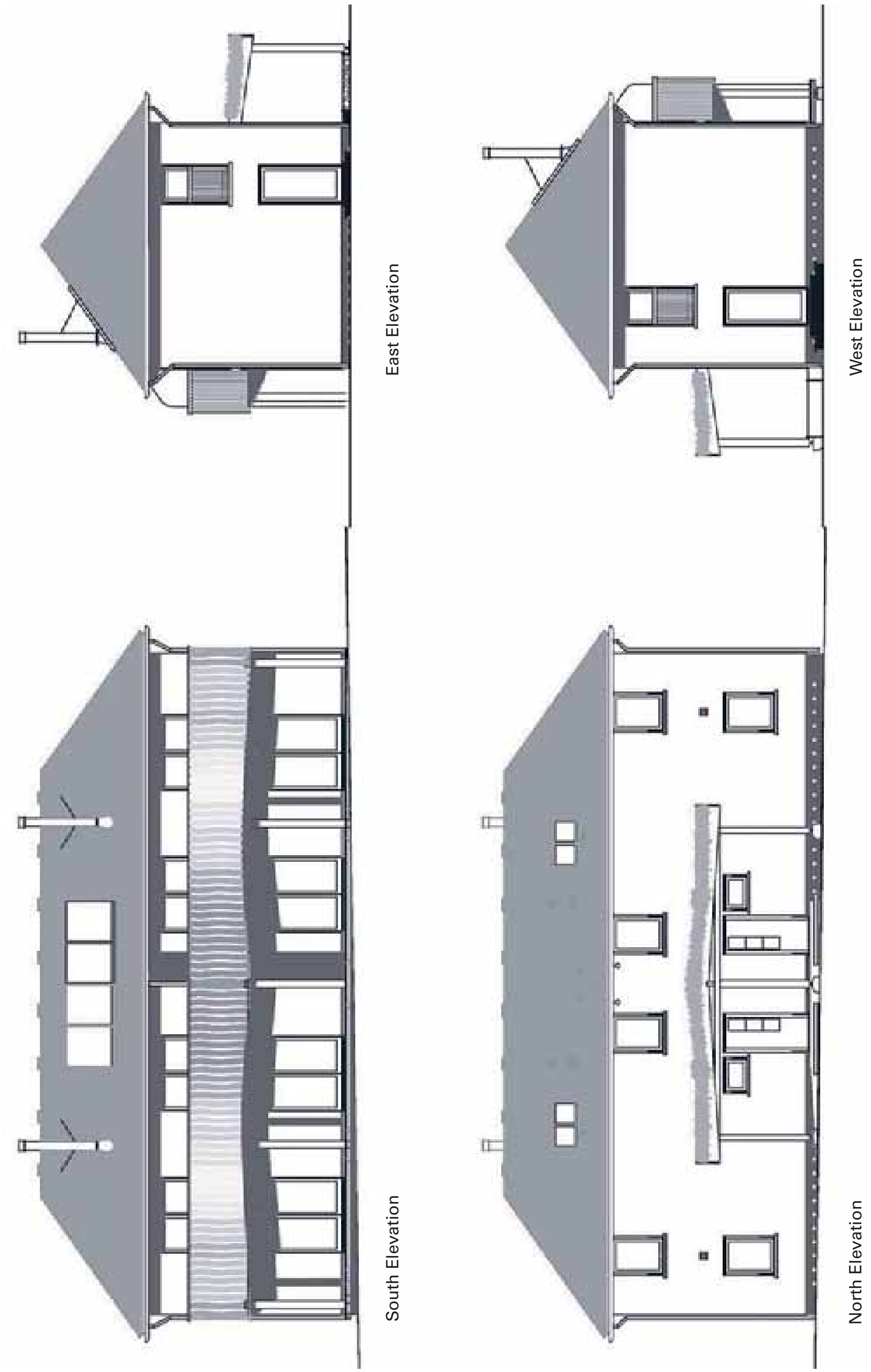
CAR TYRE FOUNDATION DETAILS



SEMI-DETACHED LOADBEARING STRAWBALE COUNCIL HOUSES: GROUND FLOOR PLAN



SEMI-DETACHED LOADBEARING STRAWBALE COUNCIL HOUSES: FIRST FLOOR PLAN



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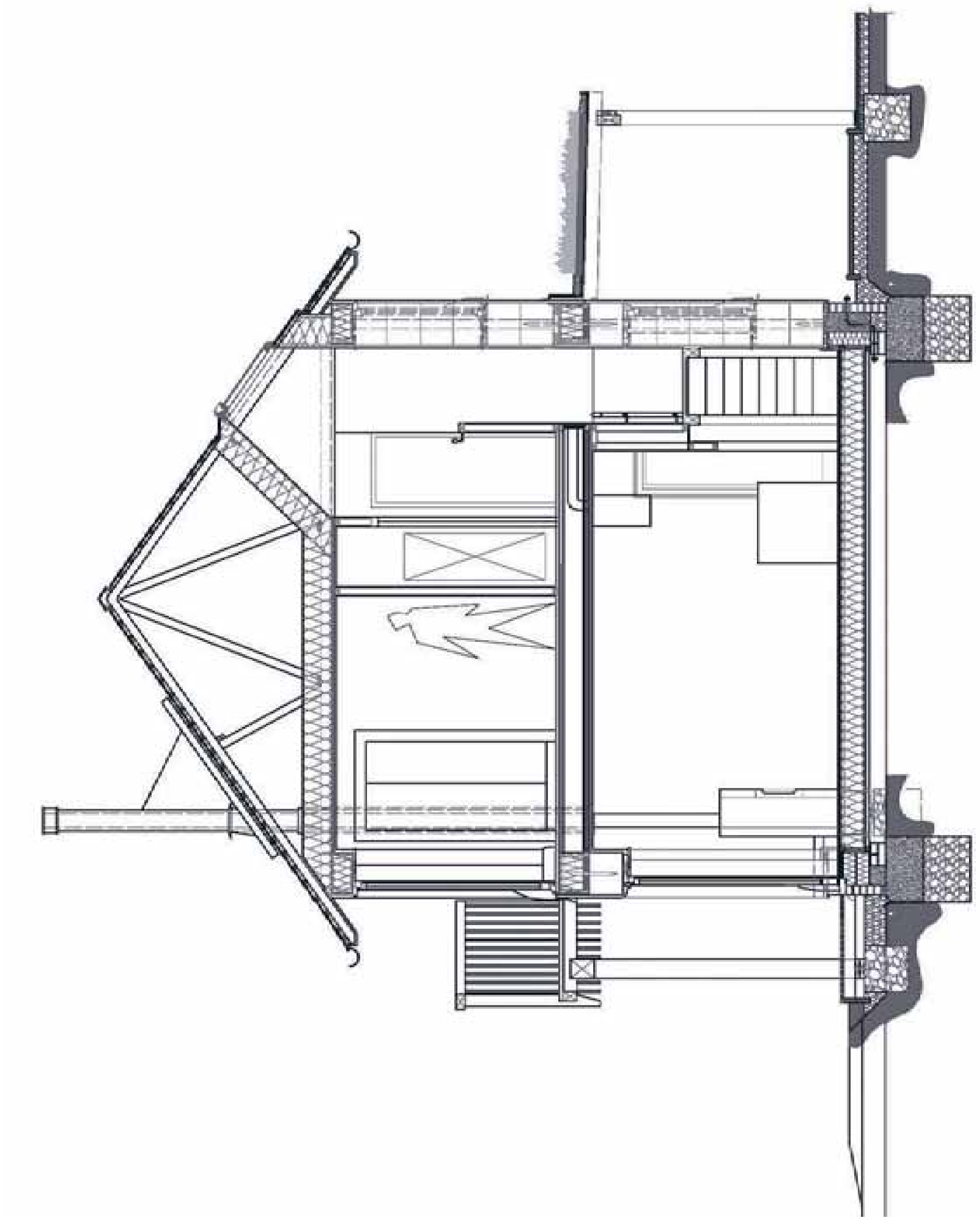
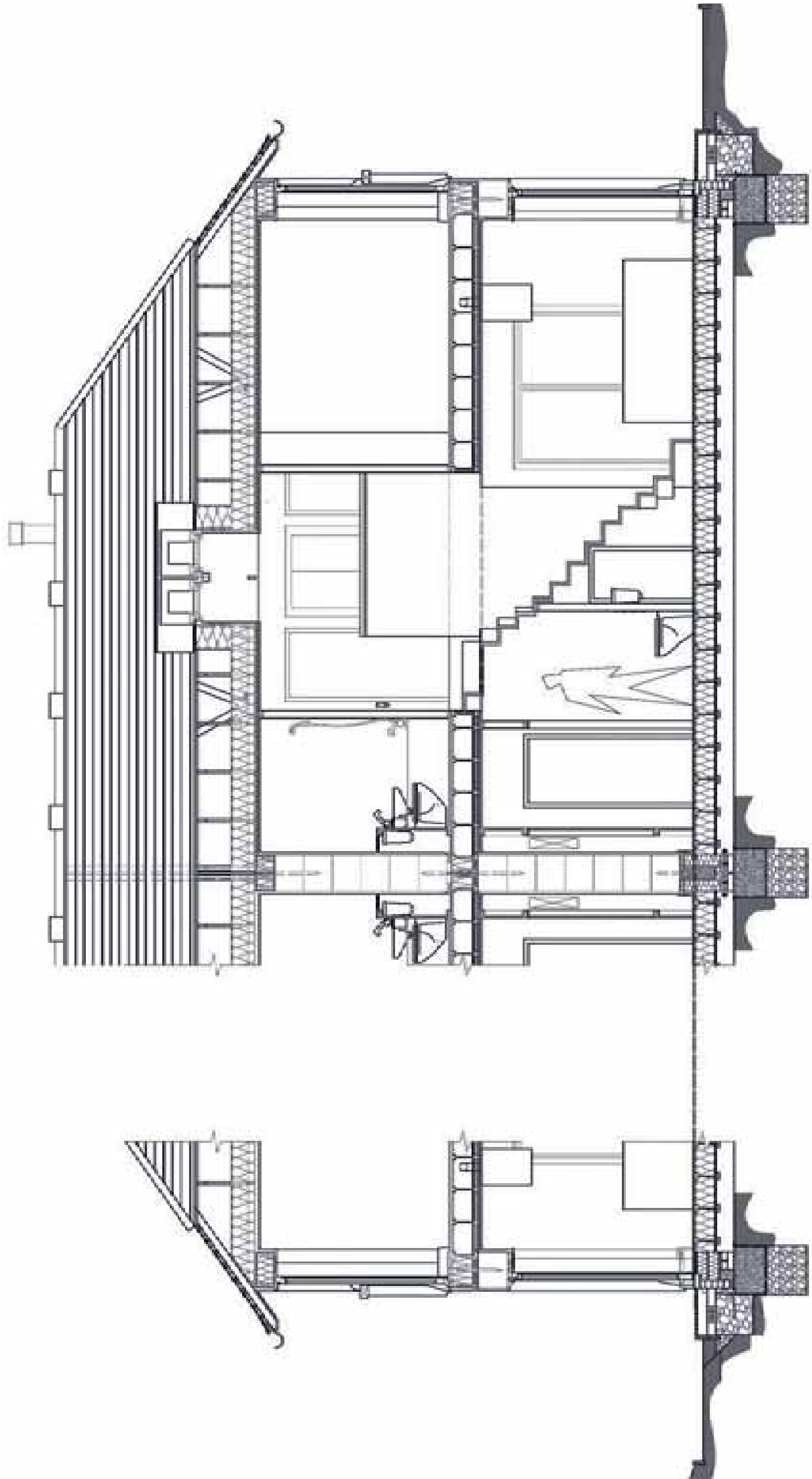


SEMI-DETACHED LOADBEARING STRAWBALE COUNCIL HOUSES: SECTION AA



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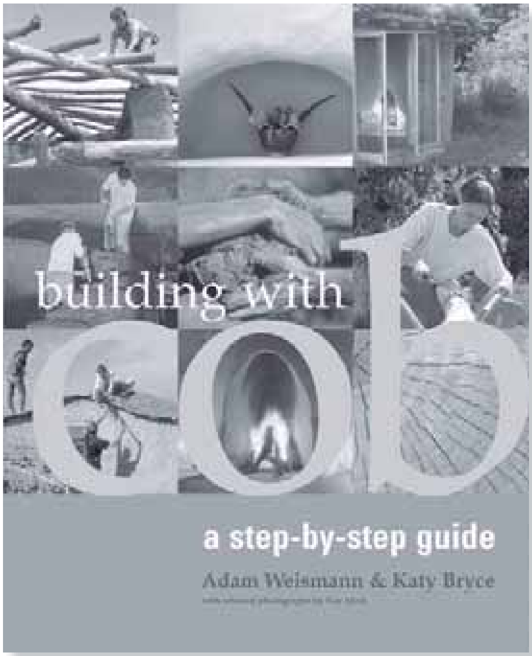


BUILDING WITH COB

A step-by-step guide

Adam Weismann and Katy Bryce

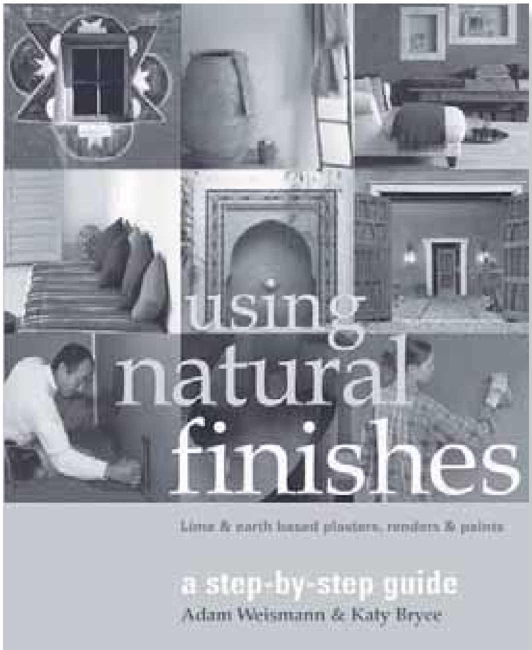
The first practical UK handbook about building with this eco-friendly material

ISBN: 978 1 903998 72 4
PRICE: £25.00 / $45.00 pb
Distributed in the USA by Chelsea Green

Cob building uses a simple mixture of clay subsoil, aggregate, straw and water to create solid structural walls built without shuttering or forms, on to a stone plinth. This ancient practice has been used throughout Britain for centuries— the fact that 45,000 of Cornwall's housing stock is cob is testament to the material's strength and durability.

Building with Cob shows how to apply cob-building techniques in a wide variety of situations. It covers everything from design, planning and siting to roofs, insulation and floors. Lavishly illustrated with inspirational colour photographs, it is the first book of its kind in the UK.

The Authors: Adam Weismann and Katy Bryce undertook an apprenticeship in natural building with the Cob Cottage Company in Oregon, USA. On their return to the UK they started their company Cob in Cornwall. They have built and restored many cob buildings, including two-storey houses, small studios and garden rooms, outside courtyards and fireplaces, and earth ovens. In 2003 they won a 'Pioneers to the Nation' award from the Queen. They live in Manaccan, Cornwall.



USING NATURAL FINISHES

Lime- and earth-based plasters, renders and paints: a step-by-step guide

Adam Weismann and Katy Bryce

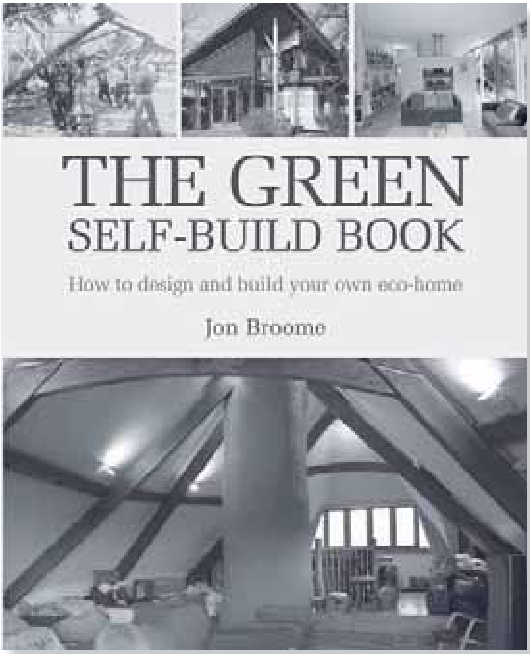
"An inspiring and practical guide"
David Pearson, author of *The New Natural House Book*

ISBN: 978 1 900322 16 4
PRICE: £20.00 / $40.00 pb
Distributed in the USA by Chelsea Green

With the increasing awareness of eco-building techniques and the growing desire to make our homes healthier, the historical benefits of using natural renders and paints are being rediscovered.

Using Natural Finishes is an in-depth guide to the selection, mixing and application of lime- and clay-based plasters, renders, paints and washes. With step-by-step instructions and detailed illustrations to show the practical elements of working with lime- and clay-based finishes, the authors demonstrate how these natural 'breathable' plasters and paints can be used on a wide variety of wall surfaces. These include traditional and eco-build materials such as cob, strawbale and stone, as well as modern plasterboard and concrete surfaces, with stunning results. Easy-to-follow DIY projects guide the reader through all aspects of using these natural finishes, with beautiful photographs of techniques and examples from the UK and abroad.

The Authors: Adam Weismann & Katy Bryce work with lime and clay on a daily basis through their company, Cob in Cornwall. They learnt these skills through restoring ancient vernacular buildings in Cornwall, and then began to apply the traditional techniques and materials to contemporary 'eco' builds. They have a passionate belief in the power of using these natural materials to benefit the health and well-being of people, buildings and the environment.



THE GREEN SELF-BUILD BOOK

How to design and build your own eco-home

Jon Broome

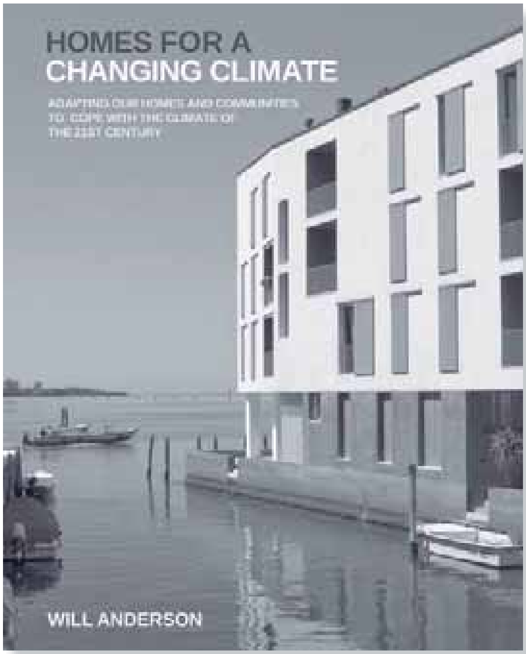
A highly illustrated, practical handbook on eco-friendly self-building

ISBN: 978 1 903998 73 1
PRICE: £25.00 / $50.00 pb
Distributed in the USA by Chelsea Green

Whether you want a turf roof, solar-powered hot water or a super-insulated (and cost-efficient) house, you need to know the essential elements of the self-build process. In *The Green Self-Build Book* Jon Broome gives an overview of the different methods of sustainable and eco-friendly construction techniques, presenting this information in a way that is relevant to non-professionals. The book includes case studies of green building techniques, such as earth and strawbale buildings.

The Green Self-Build Book gives inspiration and information to guide you through the green self-build process. It is intended for anyone who is planning a self-build project, and also for housing professionals, students and teachers.

The Author: Jon Broome is an architect who has self-built two houses. He was for many years Director of Architype, a London-based architectural practice working on housing, education, health and community buildings with specialist expertise in low-energy design, timber-frame construction and sustainable building. He is co-author of *The Self-Build Book* and contributor to *Housing & the Environment*, published by the Chartered Institute of Housing. He lives in London, where he runs his own consultancy specialising in sustainable construction.



HOMES FOR A CHANGING CLIMATE

Adapting our homes and communities to cope with the climate of the 21st century

Will Anderson

ISBN: 978 1 900332 47 8
PRICE: £20.00 / $35.00 pb
Distributed in the USA by Chelsea Green

"Our climate is changing. This fascinating book offers practical, proven examples of how, throughout history, mankind has ingeniously adapted his dwellings to the demands of the climate."
Kevin McCloud, Presenter, *Grand Designs*

The world has finally woken up to the reality of climate change. But as we work towards a secure, low-carbon future, we must address the changes that are already taking place in the planet's climate. We must learn to live with higher temperatures, intense rainstorms, rising sea levels and prolonged drought.

In Britain, occasional weather extremes tend to have serious impacts because we are simply not prepared for them. Yet across the world, communities have been living with such extremes for millennia. *Homes for a Changing Climate* celebrates this collective wisdom, exploring traditional and contemporary responses to the challenges of climate and illustrating the many ways in which houses can be designed, built and adapted to cope with these challenges. Based on the new climate projections for the UK, published by the Met Office in June 2009, the book combines inspiring case studies, striking photography and practical advice.

The Author: Will Anderson is a researcher and writer with wide interests in the environmental field. He left a long-standing career in public health to gain a degree in Energy and Sustainable Development, and subsequently built 'Tree House' in Clapham, one of Britain's few genuinely 'zero carbon' houses and the subject of his book *Diary of an Eco-Builder.* Will is now Senior Researcher at the Centre for Sustainable Energy. His website is www.treehouseclapham.org.uk.

"All you want to know about *in situ* strawbale building construction, explained in one easy-to-understand book" Tim Yates, Technical Director, BRE Ltd, and Peter Walker, Director, BRE Centre for Innovative Construction Materials, University of Bath

Strawbale building is a radically different approach to construction. Pioneered in the USA over a hundred years ago and established in the UK in the 1990s, the technique is now entering the mainstream – used by firms who see its value in terms of cost-effectiveness, ease of installation and energy efficiency. Straw has great loadbearing qualities and provides super-insulation at an affordable price.

This book is for self-builders as well as for people working in the construction industry. Strawbale building is accessible to many people who are normally excluded from the construction process, and provides immense opportunity for creative fun, enabling you to design and build the sort of shape and space you'd really like.

Building with Straw Bales explains, in straightforward and common-sense terms, the principles of strawbale building in the UK climate. It covers design principles, the different types of foundations; how to raise walls, stabilise them and protect them from the weather; and how strawbale buildings can easily meet Building Regulations requirements. This fully revised and expanded edition includes new sections on natural plasters, a detailed analysis of how straw performs with humidity, and an extensive resources section.

The author: Barbara Jones FRSA is the founder and director of amazonails, the leading UK company for strawbale design, consultancy and training. She has pioneered techniques for use in the UK climate, including the use of traditional lime and clay plasters. Awards won by amazonails buildings include the Grand Designs Eco-home of the Year in 2008 and the East of England Sustainability Award from the RICS in 2009. Amazonails' website is www.amazonails.org.uk.

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